

AEA TECHNOLOGY ENVIRONMENT (Incorporating UK National Environmental Technology Centre) (Soil Separation and Washing Process)

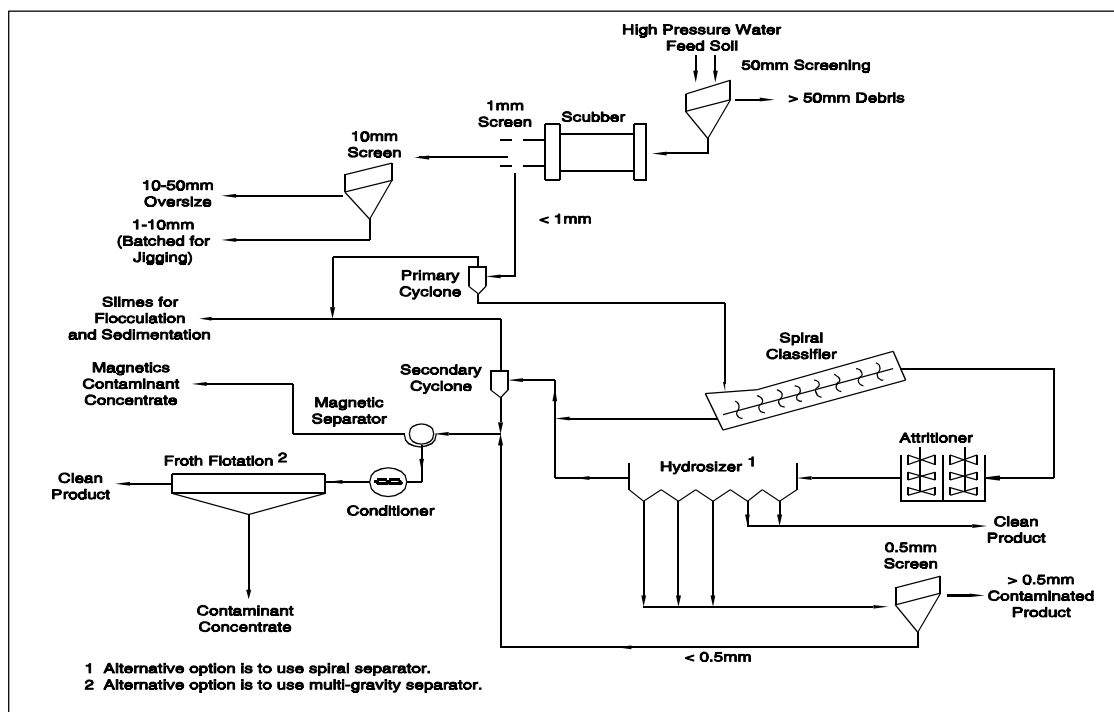
TECHNOLOGY DESCRIPTION:

AEA Technology Environment (AEA) has developed an ex situ soil separation and washing process that uses mineral processing technology and hardware. The process can be used (1) as a volume reduction process to release clean soil fractions and concentrate contaminants, or (2) as a pretreatment stage in a treatment train.

Because each contaminated soil is different, AEA has developed a custom physical treatment process for soil using a three-stage process: laboratory-scale characterization, separation testing and assessment, and treatment and data analysis.

AEA is experienced in conducting pilot plant testing programs on contaminated soil and mineral ores. In addition, AEA uses computer

software designed to reconcile material flow data. The results of data processing lead to recommendations for full-scale continuous flow sheets with predicted flows of solids, associated contaminant species, and water. Contaminant levels and distributions to the various products can also be estimated. Such data are required to estimate the cost and potential success of the full-scale remediation process plant. Flow sheet configuration is flexible and can be customized to address the nature and contamination of each soil or waste. A typical schematic flow sheet of the process is shown in the diagram on the previous page. The flow sheet involves screening the raw feed at 50 millimeters (mm) under powerful water jets to deagglomerate the mass. Debris greater than 50 mm in size is often decontaminated. Remaining solids and the water are passed through a drum scrubber that deagglomerates the mass further because agitation



Generalized Flowsheet for the Physical Treatment of Contaminated Soil

is more intense. It breaks down clay lumps and adhering material into suspension, except for surface coatings of clay and oil on fine particles. The drum scrubber discharge is screened at 1 mm, and the oversize discharge is screened at 10 mm. The 10 to 50 mm size range is often clean debris; if it is not clean then it can be crushed and re-fed to the system. Material from 1 to 10 mm is often contaminated and requires further treatment.

For all material less than 1 mm, the clay and water are removed by hydrocycloning. The fine product, less than 10 micrometers (m), is flocculated and thickened to recover the process water for recycling. Thickened clay product, usually containing concentrated contaminants, passes to further treatment or disposal. Sands from the hydrocycloning step are further dewatered in a classifier before the third and most intense deagglomeration operation.

An attrition scrubber removes the remaining surface contamination and degrades fine clayballs. Having completed deagglomeration, the soil is fractionated by particle size or separated by specific gravity. A second stream of particles less than 10 mm is removed by hydrocycloning and joins the primary product stream. Finer sands and silt are screened at 500 mm to yield a contaminated sand for disposal or retreatment. A 10 to 500 mm fraction can be separated magnetically, by flotation, by multigravity separation, or by a combination of these methods. These stages produce a contaminant concentrate, leaving the remaining material relatively contaminant free.

WASTE APPLICABILITY:

The soil separation and washing process is designed to remove metals, petroleum hydrocarbons, and polynuclear aromatic hydrocarbons from soil. The process may be applied to soils from gas and coke works, petrochemical plants, coal mines, iron and steel works, foundries, and nonferrous smelting, refining, and finishing sites. The process can also treat sediments, dredgings, sludges, mine tailings, and some industrial wastes.

STATUS:

The technology was accepted into the SITE Emerging Technology Program in July 1991 and completed in 1994. A Final Report was delivered to the U.S. EPA in 1994, and work done with this technology was presented the same year at the 87th Annual Meeting and Exhibition of the Air and Waste Management Association, the 20th Annual RREL Hazardous Waste Research Symposium, and the 5th Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International. Pilot trials were conducted on 30 tons of soil at a throughput rate of 0.5 ton per hour. Several test runs were performed to evaluate different flow sheet configurations. Reports on this technology can be obtained from the U.S. EPA.

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ARIZONA STATE UNIVERSITY/ ZENTOX CORPORATION (Photocatalytic Oxidation with Air Stripping)

TECHNOLOGY DESCRIPTION:

Chlorinated volatile organic compounds (VOC), such as trichloroethene (TCE) and tetrachloroethene (PCE), are readily removed from groundwater and soil using established methods such as air stripping and vapor extraction. However, this solution produces a VOC-contaminated air stream that requires further treatment.

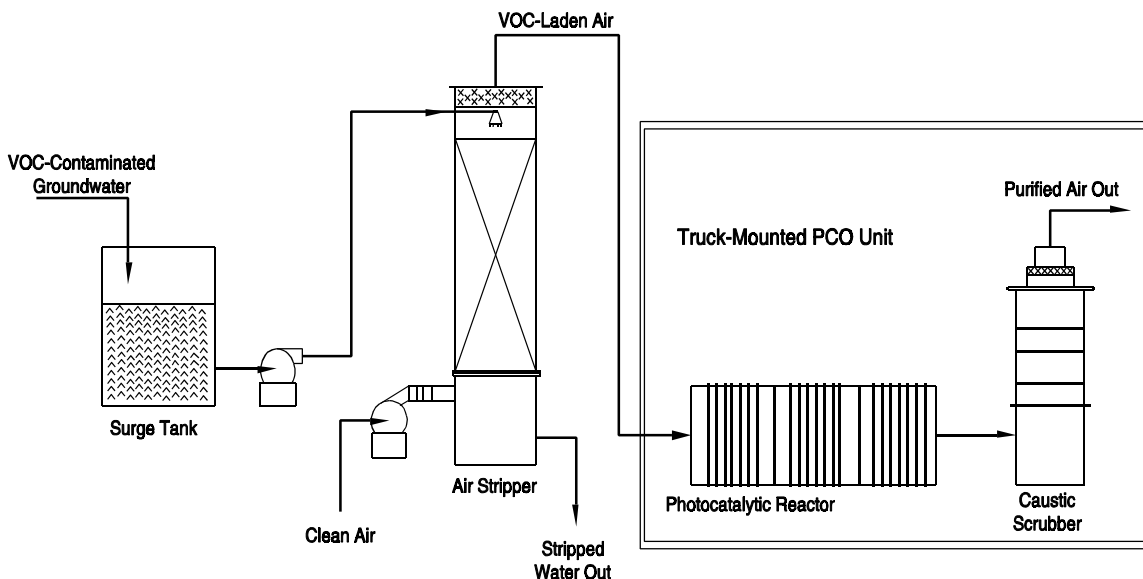
In gas-solid photocatalytic oxidation (PCO), the VOC-laden air stream is exposed to a titania catalyst in near-ultraviolet (UV) light. The UV light activates the catalyst, producing oxidizing radicals. The radicals promote rapid chain reactions that completely destroy VOCs to carbon dioxide and water; these oxidation reactions occur at or near room temperature. The treatment of chlorinated organics also produces hydrochloric acid.

Arizona State University (ASU) is investigating an integrated pilot-scale pump-and-treat system

that transfers chlorinated VOCs to an air stream using air stripping. A PCO reactor installed downstream of the air stripping unit treats the contaminated air stream. The figure below illustrates the system. The PCO unit incorporates a flow-through photocatalytic reactor for VOC destruction and a caustic absorber bed for removal of hydrochloric acid. The acid is neutralized to sodium chloride in the absorber bed.

PCO offers the following advantages over conventional treatment technologies:

- The photocatalytic process allows VOCs to be oxidized at or near room temperature.
- Low-temperature operation allows the use of plastic piping and construction, thereby reducing costs and minimizing acid corrosion problems.
- Chemical additives are not required.



Photocatalytic Oxidation with Air Stripping

- The titania catalyst and UV lamps are inexpensive and commercially available (modified catalyst formulations are available for enhanced performance).
- A variety of halogenated and nonhalogenated organic compounds can be completely oxidized to innocuous or easily neutralized products, such as carbon dioxide and hydrochloric acid.

WASTE APPLICABILITY:

This technology can treat VOC-contaminated streams generated by air stripping treatment of contaminated groundwater or soil vapor extraction of contaminated soil. The technology is appropriate for dilute VOC concentrations (such as 500 parts per million by volume or less) and low to moderate flow rates. Laboratory data indicate that the PCO technology can also be adapted for industrial facilities that emit dilute VOC-contaminated air streams. Candidates include chemical process plants, dry cleaners, painting operations, solvent cleaning operations, and wastewater and hazardous waste treatment facilities. Air in closed environments could also be purified by integrating PCO units with heating, ventilation, and air conditioning systems.

STATUS:

The PCO technology was accepted into the SITE Emerging Technology Program in 1993. Under the program, ASU has conducted bench-scale tests to evaluate the integration of a PCO unit downstream of an existing air stripping unit. Results of the bench-scale testing have provided design data for a pilot-scale test at a Phoenix, Arizona, Superfund site contaminated with chlorinated VOCs. ASU's previous laboratory studies indicate rapid destruction to nondetectable levels (98 to 99 percent removal) for various concentrations of TCE and other chlorinated ethenes in humid air streams.

In 1995, Zentox Corporation (Zentox) fielded a prototype PCO system for the treatment of TCE in air. Building on the data gained from that system, Zentox is fabricating a second generation system for use at the Phoenix site. Following tests at the Phoenix site, the 50- to 100-cubic-feet-per-minute pilot plant unit will be available for trials at other locations.

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ART INTERNATIONAL, INC. (formerly ENVIRO-SCIENCES, INC.) (Low-Energy Extraction Process)

TECHNOLOGY DESCRIPTION:

The patented Low-Energy Extraction Process (LEEP®) uses common organic solvents to concentrate and extract organic pollutants from soil, sediments, and sludges. LEEP® can treat contaminated solids to the stringent cleanup levels mandated by regulatory agencies. LEEP® includes pretreatment, washing, and concentration processes (see figure below).

During pretreatment, particles measuring up to 8 inches in diameter are removed in a gravity settler-floater. The settler-floater includes a metal detector and remover, a crusher, and a metering feeder. Floating material often found at remediation sites, such as wood chips, grass, or root material, is also removed.

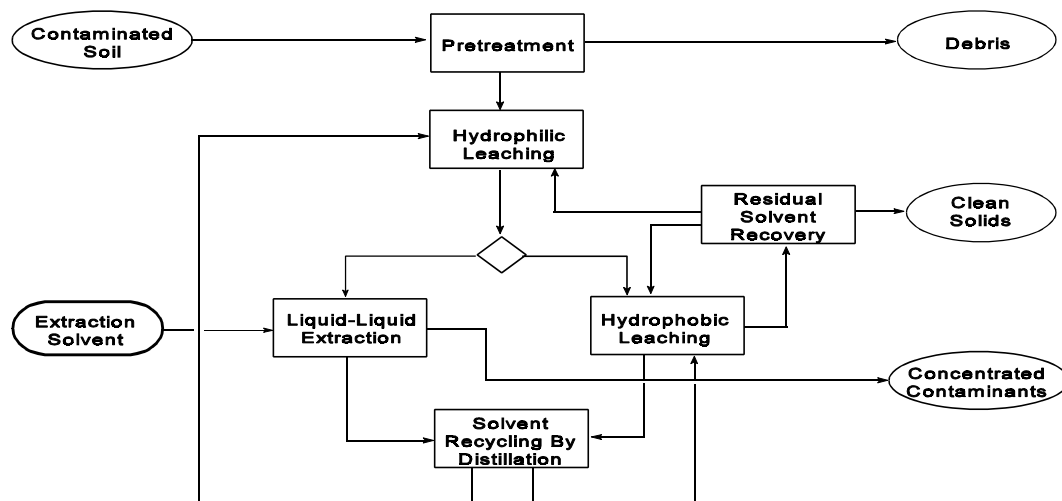
After pretreatment, the solid matrix is washed in a unique, dual solvent process that uses both hydrophilic and hydrophobic solvents. The combination of these proprietary solvents guarantees efficient contaminant removal.

The extracted pollutants are then concentrated in a sacrificial solvent by liquid-liquid extraction or by distillation, before being removed from the process for off-site disposal or recycling. The treated solids can be returned to the site as clean fill.

LEEP® is a low-pressure process operated at near-ambient conditions. It is designed as a closed-loop, self-contained, mobile unit consisting of proven heavy-duty equipment. The relatively inexpensive solvents used in the process are recycled internally. The solvents are applicable to almost every type of organic contaminant, and their physical properties enhance clay and silt particle settling.

WASTE APPLICABILITY:

LEEP® can treat most organic contaminants in soil, sediment, and sludge, including tar, creosote, chlorinated hydrocarbons, polynuclear aromatic hydrocarbons, pesticides, and wood- preserving chlorophenol formulations. Bench- and pilot-scale experiments have shown that



LEEP® Process Flow Diagram

LEEP® effectively treats tar-contaminated solids from manufactured gas plant sites, soils and sediments contaminated with polychlorinated biphenyls and refinery waste sludges, and soils contaminated with petroleum hydrocarbons.

STATUS:

LEEP® was accepted into the Emerging Technology Program in July 1989. Bench-scale studies for process development were completed in 1994. A draft report that details the evaluation results has been submitted to EPA. The final report will be available in 1997.

In addition, ART International, Inc., routinely conducts bench-scale treatability studies for government and industrial clients, and it has obtained Toxic Substances Control Act, Resource Conservation and Recovery Act, and air permits for the technology. Other developments include the following:

- A 200-pound-per-hour pilot-scale unit has been constructed.
- Tests of the pilot-scale unit indicated that LEEP® can treat soil from manufactured gas plant sites containing up to 5 percent tar.

- Tests to scale up the pilot-scale unit to a commercial unit are complete.
- Commercial design criteria and a turnkey bid package are complete.
- Commercialization activities for a full-scale unit are underway.
- In 1994, Soil Extraction Technologies, Inc., a wholly owned subsidiary of Public Service Electric & Gas, purchased a LEEP® license.

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ATOMIC ENERGY OF CANADA, LIMITED (Chemical Treatment and Ultrafiltration)

TECHNOLOGY DESCRIPTION:

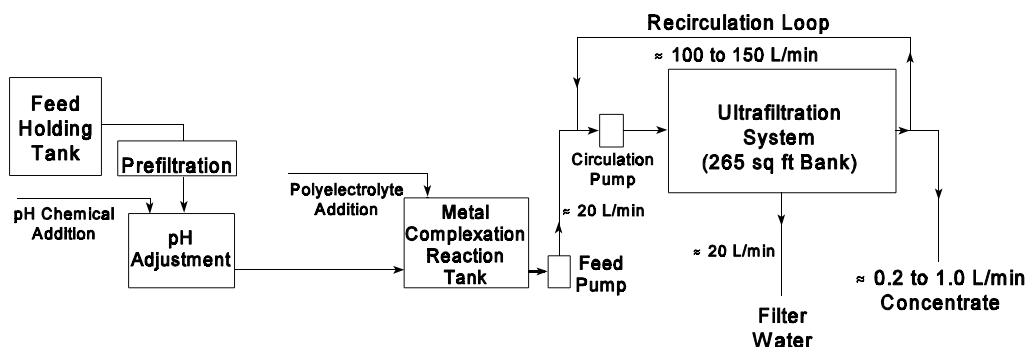
The Atomic Energy of Canada, Limited (AECL), process uses chemical pretreatment and ultrafiltration to remove trace concentrations of dissolved metals from wastewater, contaminated groundwater, and leachate. The process selectively removes metal contaminants and produces a volume-reduced water stream for further treatment and disposal.

The installed unit's overall dimensions are 5 feet wide by 7 feet long by 6 feet high. The skid-mounted unit consists of (1) a bank of 5-micron cartridge prefilters, (2) a feed conditioning system with polyelectrolytes and chemicals for pH adjustment, (3) two banks of hollow-fiber ultrafilters, (4) a backflush system for cleaning the membrane unit, and (5) associated tanks and instrumentation.

The figure below illustrates the process. Wastewater enters the prefilter through the feed holding tank, where suspended particles are removed from the feed. The filtered waste stream is then routed to conditioning tanks where the solution pH is adjusted. Water-soluble

macromolecular compounds are then added to the wastewater to form complexes with heavy metal ions. Next, a relatively high molecular weight polymer, generally a commercially available polyelectrolyte, is added to the wastewater to form selective metal-polymer complexes at the desired pH and temperature. The polyelectrolyte quantities depend on the metal ion concentration.

The wastewater then passes through a cross-flow ultrafiltration membrane system by way of a recirculation loop. The ultrafiltration system provides a total membrane surface area of 265 square feet and a flow rate of about 6 gallons per minute (gpm). The membranes retain the metal complexes (in the concentrate), while allowing uncomplexed ions to pass through the membrane with the filtered water. The filtered water (the permeate) is continuously withdrawn, while the concentrate stream containing most of the contaminants is recycled until it meets the target concentration. After reaching the target concentration, the concentrate stream is withdrawn for further treatment, such as solidification. It can then be safely disposed of, while the clean filtered water is discharged.



Single-Stage Chemical Treatment and Ultrafiltration Process

WASTE APPLICABILITY:

The AECL process treats groundwater, leachate, and surface runoff contaminated with trace levels of toxic heavy metals. The process also treats effluents from (1) industrial processes, (2) production and processing of base metals, (3) smelters, (4) electrolysis operations, and (5) battery manufacturing. Potential applications include removal of metals such as cadmium, lead, mercury, uranium, manganese, nickel, chromium, and silver.

The process can treat influent with dissolved metal concentrations from several parts per million (ppm) up to about 100 ppm. The process also removes other inorganic and organic materials present as suspended or colloidal solids. The sole residue is the ultrafiltration concentrate, which generally constitutes 5 to 20 percent of the feed volume.

STATUS:

The AECL process was accepted into the SITE Emerging Technology Program in 1988. During initial bench- and pilot-scale tests, the AECL process successfully removed cadmium, lead, and mercury. These results were used to help designers construct the mobile unit.

The mobile unit has been tested at Chalk River Laboratories and at a uranium mine tailings site in Ontario, Canada. The field evaluation indicated that process water characteristics needed further study; pretreatment schemes are being evaluated. The mobile unit, which is capable of treating influent flows ranging from 1,000 to 5,000 gallons per day, is available for treatability tests and on-site applications. An Emerging Technology Bulletin (EPA/540/F-92/002) is available from EPA.

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ATOMIC ENERGY OF CANADA LIMITED (Ultrasonic-Aided Leachate Treatment)

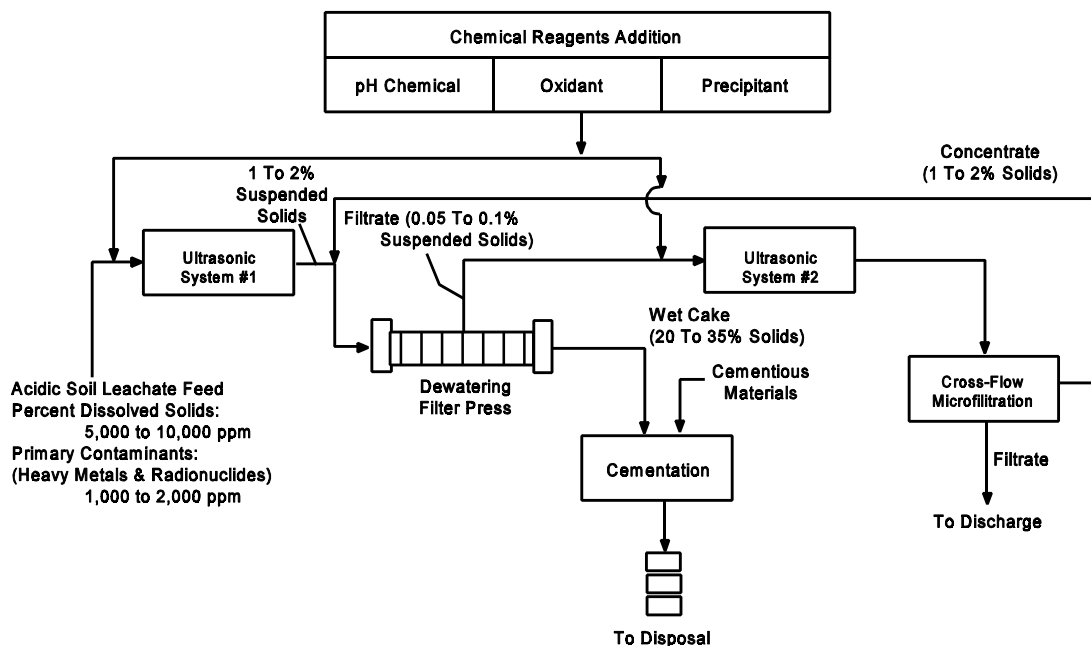
TECHNOLOGY DESCRIPTION:

The ultrasonic-aided leachate treatment process involves enhanced chemical treatment of acidic soil leachate solutions. These solutions, also known as acid mine drainage, are caused by the oxidation and dissolution of sulfide-bearing wastes that produce sulfuric acid. The resulting acidic water leaches metal contaminants from the exposed waste rock and mine tailings, creating large volumes of toxic acidic leachates.

The ultrasonic-aided leachate treatment process uses an ultrasonic field to improve contaminant removal through precipitation, coprecipitation, oxidation, ion scavenging, and sorption (see figure below). These processes are followed by solid-liquid separation using a filter press and a cross-flow microfilter connected in series. The

time required for treatment depends on (1) the nature of acidic waste to be treated, (2) the treated water quality with respect to contaminant concentration, and (3) the rate at which the physical and chemical processes occur. The treatable leachate volume is scalable.

The major difference between this technology and conventional processes is the use of ultrasonic mixing instead of mechanical agitation in large tanks. Research indicates that an ultrasonic field significantly increases both the conversion rate of dissolved contaminants to precipitates and the rate of oxidation and ion exchange. Earlier studies by Atomic Energy of Canada Limited (AECL) revealed that the time required to precipitate heavy metals from aqueous solutions decreased by an order of magnitude in the presence of an ultrasonic field.



Single-Stage Chemical Treatment and Ultrafiltration Process

The ultrasonic-aided leachate treatment process is compact, portable, and energy-efficient. Safety and process controls are built in as necessary for handling mixed radioactive solutions. The process also generates minimal fugitive emissions and produces a treated effluent that meets applicable discharge limits. The process may also be able to treat waste containing small amounts of dissolved or suspended organics.

WASTE APPLICABILITY:

The ultrasonic-aided leachate treatment process treats acid mine drainage contaminated with heavy metals and radionuclides. The process can also be combined with soil remediation technologies.

STATUS:

The ultrasonic-aided leachate treatment process was accepted into the SITE Emerging Technology Program in 1993. Under this program, AECL is developing and testing a pilot-scale unit to treat acidic soil leachate solutions containing low levels of metals and radionuclides.

The quality assurance and test plan was approved in October 1994. Laboratory-scale testing using acidic leachates from the Berkeley Pit in Butte, Montana, and from Stanleigh Mines in Elliot Lake, Ontario, Canada, is complete. The tests were designed to find optimal single and multistage treatment regimes to remove from the leachates a variety of dissolved species (such as iron, aluminum, manganese, magnesium, copper, zinc, uranium, radium, and sulfate), either as contaminants or as reusable resources.

Given optimum process chemistry, low energy (less than 5 kilojoules per liter), and low frequency (20 kilohertz), ultrasonic cavitation fields were sufficient to remove the dissolved species to levels meeting discharge requirements.

The energy input corresponds to a chemical conditioning time of a few seconds to tens of seconds. The underlying principles examined include lime and limestone precipitation, copper cementation, iron, and uranium oxidation, ion sorption, and ion scavenging.

A Phase 1 interim report summarizing the laboratory-scale results was issued in August 1995. A revised Phase 1 report was issued in February 1996. Testing of the pilot-scale system was December 1996.

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BATTELLE MEMORIAL INSTITUTE (In Situ Electroacoustic Soil Decontamination)

TECHNOLOGY DESCRIPTION:

This patented in situ electroacoustic soil decontamination (ESD) technology removes heavy metals from soils through direct current electrical and acoustic fields. Direct current facilitates liquid transport through soils. The technology consists of electrodes, an anode and a cathode, and an acoustic source (see figure below).

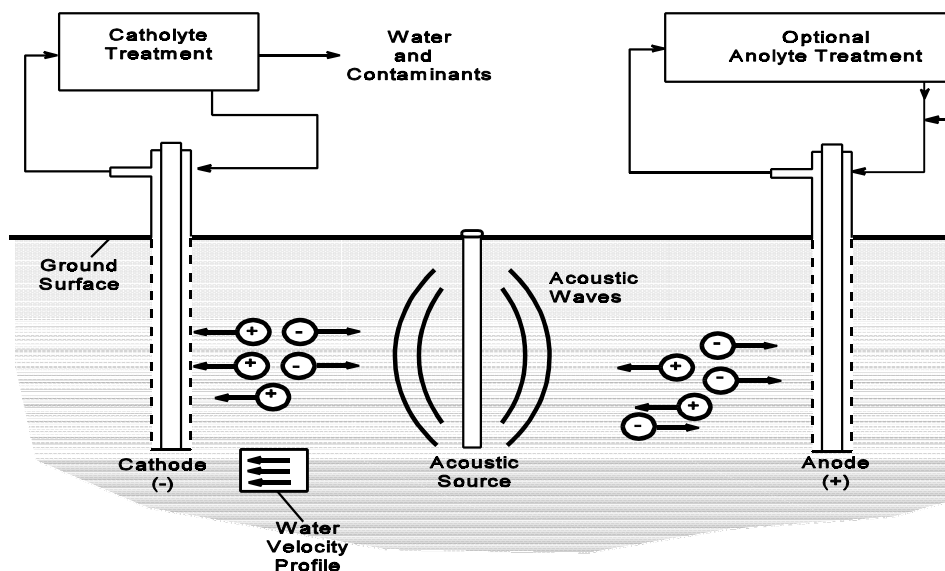
The double-layer boundary theory is important when an electric potential is applied to soils. For soil particles, the double layer consists of (1) a fixed layer of negative ions that are firmly held to the solid phase, and (2) a diffuse layer of more loosely held cations and anions. Applying an electric potential to the double layer displaces the loosely held ions to their respective electrodes. The cations take water with them as they move toward the cathode.

Besides water transport through wet soils, the direct current produces other effects, such as ion transfer, pH gradients development, electrolysis, oxidation and reduction, and heat generation.

Heavy metals present in contaminated soils can be leached or precipitated out of solution by electrolysis, oxidation and reduction reactions, or ionic migration. The soil contaminants may be (1) cations, such as cadmium, chromium, and lead; or (2) anions, such as cyanide, chromate, and dichromate. The existence of these ions in their respective oxidation states depends on soil pH and concentration gradients. Direct current is expected to increase the leaching rate and precipitate the heavy metals out of solution by establishing appropriate pH and osmotic gradients.

WASTE APPLICABILITY:

This technology removes heavy metals from soils. When applied in conjunction with an electric field and water flow, an acoustic field can enhance waste dewatering or leaching. This phenomenon is not fully understood. Another possible application involves the unclogging of recovery wells. Because contaminated particles are driven to the recovery well, the pores and interstitial spaces in the soil can close. This technology could be used to clear these clogged spaces.



In Situ Electroacoustic Soil Decontamination

The technology's potential for improving nonaqueous phase liquid contaminant recovery and in situ removal of heavy metals needs to be tested at the pilot-scale level using clay soils.

STATUS:

The ESD technology was accepted into the SITE Emerging Technology Program in 1988. Results indicate that ESD is technically feasible for removing inorganic species such as zinc and cadmium from clay soils; however, it is only marginally effective for hydrocarbon removal. A modified ESD process for more effective hydrocarbon removal has been developed but has not been tested. The Emerging Technology Report (EPA/540/5-90/004) describing the 1-year investigation can be purchased through the National Technical Information Service, (PB 90-204728/AS). The Emerging Technology Summary (EPA/540/S5-90/004) is available from U. S. EPA.

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BIOTROL® (Methanotrophic Bioreactor System)

TECHNOLOGY DESCRIPTION:

The BioTrol methanotrophic bioreactor system is an aboveground remedial technology for water contaminated with halogenated hydrocarbons. Trichloroethene (TCE) and related compounds pose a difficult challenge to biological treatment. Unlike aromatic hydrocarbons, for example, TCE cannot serve as a primary substrate for bacterial growth. Degradation depends on cometabolism (see figure below), which is attributed to the broad substrate specificity of certain bacterial enzyme systems. Although many aerobic enzyme systems reportedly cooxidize TCE and related compounds, BioTrol claims that the methane monooxygenase (MMO) produced by methanotrophic bacteria is the most promising.

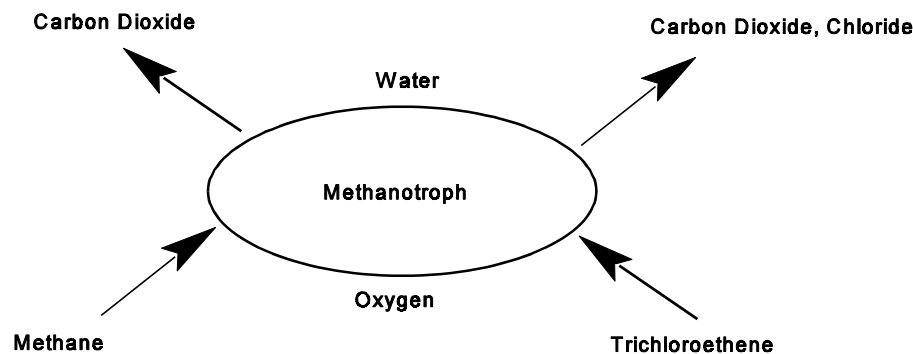
Methanotrophs are bacteria that can use methane as a sole source of carbon and energy. Although certain methanotrophs can express MMO in either a soluble or particulate (membrane-bound) form, BioTrol has discovered that the soluble form used in the BioTrol process induces extremely rapid

TCE degradation rates. Two patents have been obtained, and an additional patent on the process is pending. Results from experiments with *Methylosinus trichosporium* strain OB3b indicate that the maximum specific TCE degradation rate is 1.3 grams of TCE per gram of cells (dry weight) per hour. This rate is 100 to 1,000 times faster than reported TCE degradation rates for nonmethanotrophs. This species of methanotrophic bacteria reportedly removes various chlorinated aliphatic compounds by more than 99.9 percent.

BioTrol has also developed a colorimetric assay that verifies the presence of MMO in the bioreactor culture.

WASTE APPLICABILITY:

The bioreactor system can treat water contaminated with halogenated aliphatic hydrocarbons, including TCE, dichloroethene isomers, vinyl chloride, chloroform, dichloromethane (methylene chloride), and others. In the case of groundwater treatment,



Cometabolism of TCE

bioreactor effluent can either be reinjected or discharged to a sanitary sewer under a National Pollutant Discharge Elimination System permit.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. Bench- and pilot-scale tests were conducted using a continuous-flow, dispersed-growth system. As shown in the figure below, the pilot-scale reactor displayed first-order TCE degradation kinetics. The final report on the demonstration appears in the *Journal of the Air and Waste Management Association*, Volume 45, No. 1, January 1995. The Emerging Technology Bulletin (EPA/540/F-93/506) and the Emerging Technology Summary (EPA/540/SR-93/505) are available from U. S. EPA.

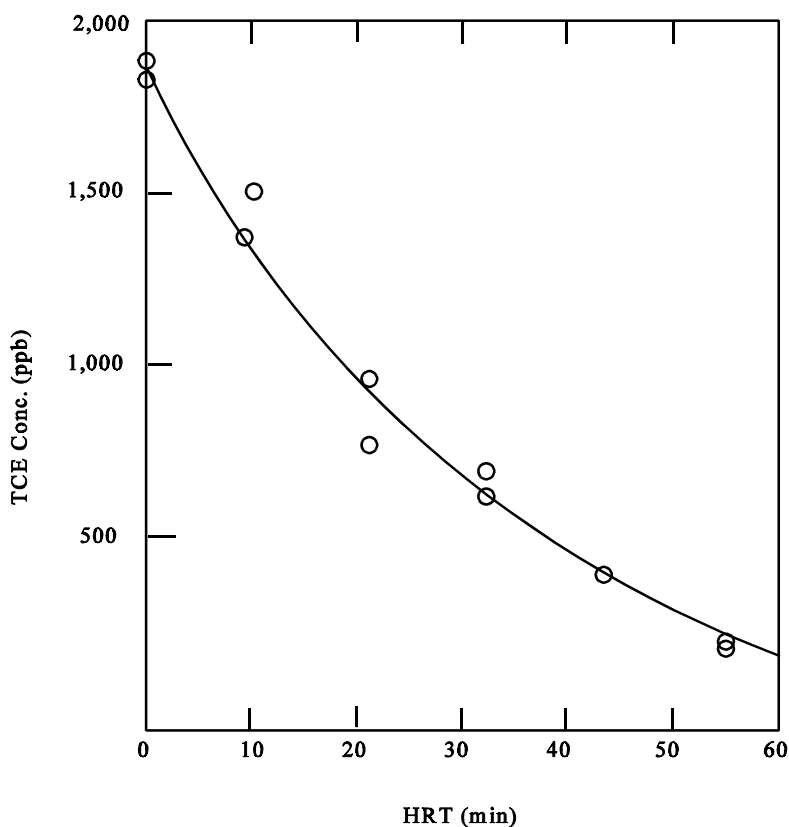
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Results for Pilot-Scale, Continuous-Flow Reactor

CENTER FOR HAZARDOUS MATERIALS RESEARCH (Acid Extraction Treatment System)

TECHNOLOGY DESCRIPTION:

The acid extraction treatment system (AETS) uses hydrochloric acid to extract heavy metal contaminants from soils. Following treatment, the clean soil may be returned to the site or used as fill.

A simplified block flow diagram of the AETS is shown below. First, soils are screened to remove coarse solids. These solids, typically greater than 4 millimeters in size, are relatively clean and require at most a simple rinse with water or detergent to remove smaller attached particles.

After coarse particle removal, the remaining soil is scrubbed in an attrition scrubber to break up agglomerates and cleanse surfaces. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones.

When extraction is complete, the solids are transferred to the rinse system. The soils are rinsed with water to remove entrained acid and metals. The extraction solution and rinse waters are regenerated using a proprietary technology that removes the metals and reforms the acid. The heavy metals are concentrated in a form potentially suitable for recovery. During the final step, the soils are mixed with lime and

fertilizer to neutralize any residual acid. No wastewater streams are generated by the process.

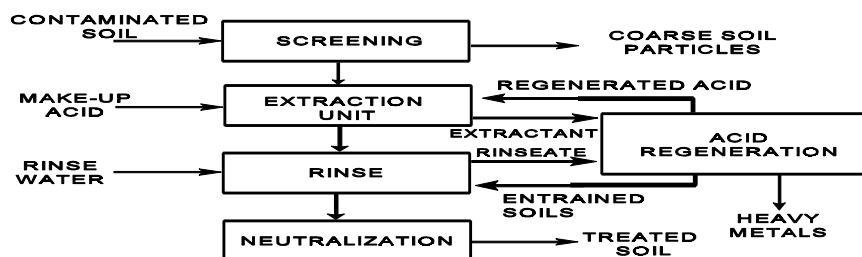
WASTE APPLICABILITY:

The main application of AETS is extraction of heavy metals from soils. The system has been tested using a variety of soils containing one or more of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The treatment capacity is expected to range up to 30 tons per hour. AETS can treat all soil fractions, including fines.

The major residuals from AETS treatment include the cleaned soil, which is suitable for fill or for return to the site, and the heavy metal concentrate. Depending on the concentration of heavy metals, the mixtures of heavy metals found at the site, and the presence of other compounds (calcium, sodium) with the metals, heavy metals may be reclaimed from the concentrate.

STATUS:

Under the Emerging Technology Program, laboratory-scale and bench-scale tests were conducted to develop the AETS technology. The bench-scale pilot system was constructed to process between 20 and 100 kilograms of soil per hour. Five soils were tested, including an EPA synthetic soil matrix (SSM) and soils from four Superfund sites, including NL Industries in Pedricktown, New Jersey; King of Prussia site in Winslow Township, New Jersey; a smelter site in Butte, Montana; and Palmerton Zinc site in



Acid Extraction Treatment System (AETS) Process

Palmerton, Pennsylvania. These soils contained elevated concentrations of some or all of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The table below summarizes soil treatability results based on the EPA Resource Conservation and Recovery Act (RCRA) hazardous waste requirements for toxicity characteristic leaching procedure (TCLP) and the California standards for total metal concentrations. The Emerging Technology Report (EPA/540/R-94/513) and Emerging Technology Summary (EPA/540/SR-94/513) are available from EPA.

The results of the study are summarized below:

- AETS can treat a wide range of soils containing a wide range of heavy metals to reduce the TCLP below the RCRA limit. AETS can also reduce the total metals concentrations below the California-mandated total metals limitations.
- In most cases, AETS can treat the entire soil, without separate stabilization and disposal for fines or clay particles, to the required TCLP and total metal limits. The only exception was the SSM, which may require separate stabilization and disposal of 20 percent of the soil to reduce the total TCLP lead concentrations

appropriately. However, AETS successfully treated arsenic, cadmium, chromium, copper, nickel, and zinc in the soil.

- Treatment costs under expected process conditions range from \$100 to \$180 per cubic yard of soil, depending on the site size, soil types, and contaminant concentrations. Operating costs ranged from \$50 to \$80 per cubic yard.

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Metal	Soil				
	SSM	Butte	King of Prussia	Pedricktown	Palmerton
As	*,T,L	*,T,L			
Cd	*,T				*,T,L
Cr	*,T,L		*,T,L	*,T,L	
Cu	*,T,L	*,T,L	*,T,L		*,T,L
Ni	*,T,L		*,T,L		
Pb	*	*,T,L		*,T,L	*,T,L
Zn	*,T,L	*,T,L		*,T,L	*,T,L

Key: * -- Metal is present in that soil
T -- Successful treatment for total metals
L -- Reduction in leachability to below standards

Boldface and larger font indicates high initial metals concentration (at least double the regulatory standards)

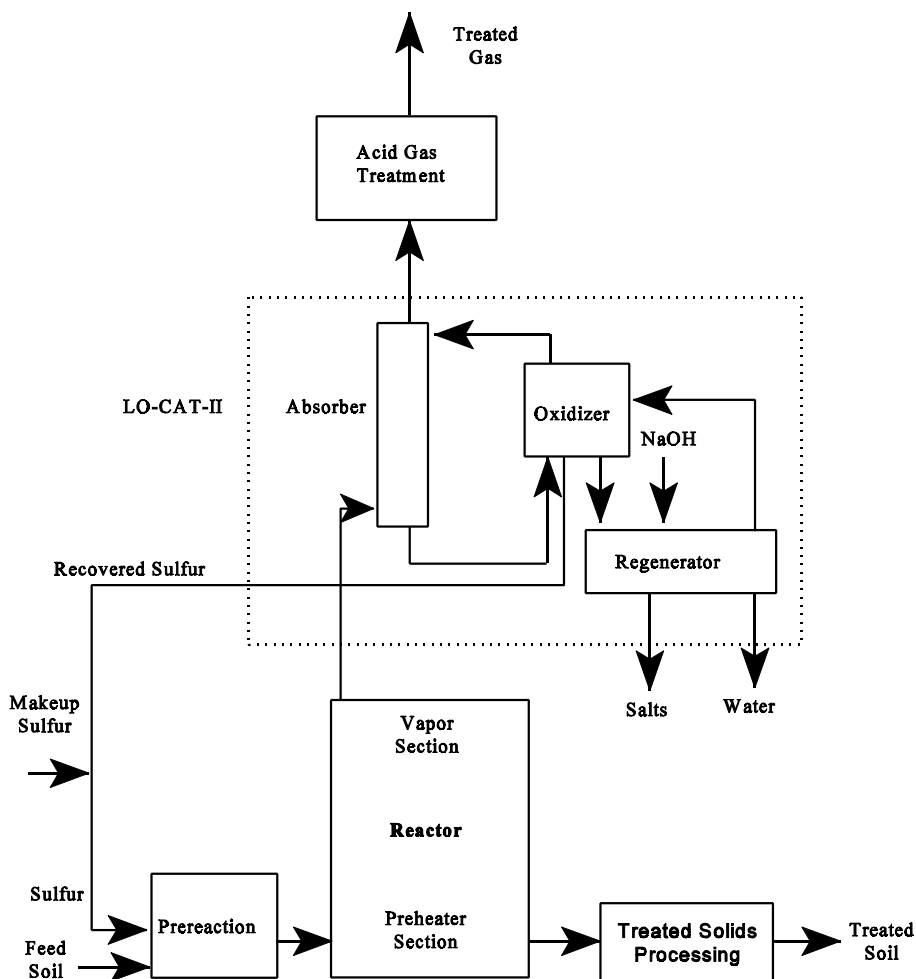
CENTER FOR HAZARDOUS MATERIALS RESEARCH (Organics Destruction and Metals Stabilization)

TECHNOLOGY DESCRIPTION:

This technology is designed to destroy hazardous organics in soils while simultaneously stabilizing metals and metal ions (see figure below). The technology causes contaminated liquids, soils, and sludges to react with elemental sulfur at elevated temperatures. All organic compounds react with sulfur. Hydrocarbons are converted to an inert carbon-sulfur powdered residue and hydrogen sulfide gas; treated chlorinated

hydrocarbons also produce hydrochloric acid gas. These acid gases are recovered from the off-gases. The hydrogen sulfide is oxidized in a conventional acid gas treating unit (such as ARI Technologies LO-CAT™), recovering the sulfur for reuse.

In addition to destroying organic compounds, the technology converts heavy metals to sulfides, which are rendered less leachable. If required, the sulfides can be further stabilized before



Organics Destruction and Metals Stabilization

disposal. Thus, heavy metals can be stabilized in the same process step as the organics destruction. The technology's main process components consist of the following:

- A prereaction mixer where the solid and reagent are mixed
- An indirectly heated, enclosed reactor that includes a preheater section to drive off water, and two integrated reactor sections to react liquid sulfur with the solids and further react desorbed organic compounds with vapor-phase sulfur
- An acid gas treatment system that removes the acid gases and recovers sulfur by oxidizing the hydrogen sulfide
- A treated solids processing unit that recovers excess reagent and prepares the treated product to comply with on-site disposal requirements

Initial pilot-scale testing of the technology has demonstrated that organic contaminants can be destroyed in the vapor phase with elemental sulfur. Tetrachloroethene, trichloroethene, and polychlorinated biphenyls were among the organic compounds destroyed.

Batch treatability tests of contaminated soil mixtures have demonstrated organics destruction and immobilization of various heavy metals. Immobilization of heavy metals is determined by the concentration of the metals in leachate compared to EPA toxicity characteristic leaching procedure (TCLP) regulatory limits. Following treatment, cadmium, copper, lead, nickel, and zinc were significantly reduced compared to TCLP values. In treatability tests with approximately 700 parts per million of Aroclor 1260, destruction levels of 99.0 to 99.95 percent were achieved. Destruction of a pesticide, malathion, was also demonstrated. The process was also demonstrated to be effective on soil from manufactured gas plants, containing a wide range of polynuclear aromatics.

The current tests are providing a more detailed definition of the process limits, metal concentrations, and soil types required for stabilization of various heavy metals to meet the limits specified by TCLP. In addition, several process enhancements are being evaluated to expand the range of applicability.

WASTE APPLICABILITY:

The technology is applicable to soils and sediments contaminated with both organics and heavy metals.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in January 1993. Bench-scale testing in batch reactors was completed in 1993. The pilot-scale program was directed at integrating the process concepts and obtaining process data in a continuous unit. The program was completed in 1995 and the Emerging Technology Report will be available in 1997.

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COGNIS, INC. (Biological/Chemical Treatment)

TECHNOLOGY DESCRIPTION:

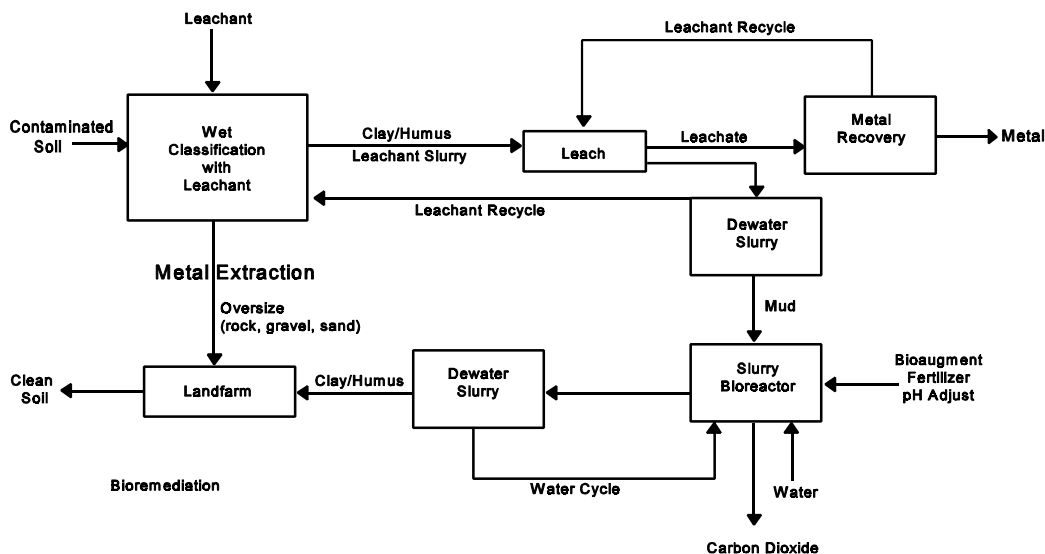
The COGNIS, Inc. biological/chemical treatment is a two-stage process that treats soils, sediments, and other media contaminated with metals and organics. Metals are first removed from the contaminated matrix by a chemical leaching process. Organics are then removed by bioremediation.

Although metals removal usually occurs in the first stage, bioremediation may be performed first if organic contamination levels are found to inhibit the metals extraction process. Bioremediation is more effective if the metal concentrations in the soil are sufficiently low so as not to inhibit microbial activity. However, even in the presence of inhibitory metal concentrations, a microbe population may be enriched to perform the necessary bioremediation.

Soil handling requirements for both stages are similar, so unit operations are fully reversible.

The final treatment products are a recovered metal or metal salt, biodegraded organic compounds, and clean soil. Contaminated soil is first exposed to a leachant solution and classified by particle size (see figure below). Size classification allows oversized rock, gravel, and sand to be quickly cleaned and separated from the sediment fines (such as silt, clay, and humus), which require longer leaching times. Typically, organic pollutants are also attached to the fines.

After dissolution of the metal compounds, metal ions such as zinc, lead, and cadmium are removed from the aqueous leachate by liquid ion exchange, resin ion exchange, or reduction. At this point, the aqueous leaching solution is freed of metals and can be reused to leach additional metal from the contaminated soil. If an extraction agent is used, it is later stripped of the bound metal and the agent is fully regenerated and recycled. Heavy metals are recovered in a saleable, concentrated form as solid metal or a metal salt. The method of metals recovery



Metal Leaching and Bioremediation Process

depends on the metals present and their concentrations.

After metals extraction is complete, the "mud" slurry settles and is neutralized. Liquids are returned to the classifier, and the partially treated soil is transferred to a slurry bioreactor, a slurry-phase treatment lagoon, or a closed land treatment cell for bioremediation. The soil and the residual leachate solution are treated to maximize contaminant biodegradation. Nutrients are added to support microbial growth, and the most readily biodegradable organic compounds are aerobically degraded.

Bench-scale tests indicate that this process can remediate a variety of heavy metals and organic pollutants. The combined process is less expensive than separate metals removal and organic remediation.

WASTE APPLICABILITY:

This remediation process is intended to treat combined-waste soils contaminated by heavy metals and organic compounds. The process can treat contaminants including lead, cadmium, zinc, and copper, as well as petroleum hydrocarbons and polynuclear aromatic hydrocarbons that are subject to aerobic microbial degradation. The combined process can also be modified to extract mercury and other metals, and to degrade more recalcitrant halogenated hydrocarbons.

STATUS:

This remediation process was accepted into the SITE Emerging Technology Program in August 1992. Bench- and pilot-scale testing of the bioremediation process is complete. A full-scale field test of the metals extraction process was completed under the Demonstration Program. For further information on the full-scale process, refer to the profile in the Demonstration Program section.

This remediation process is no longer available through COGNIS, Inc. For further information about the process, contact the EPA Project Manager.

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CONCURRENT TECHNOLOGIES (Formerly Center for Hazardous Materials Research) (Smelting Lead-Containing Waste)

TECHNOLOGY DESCRIPTION:

Secondary lead smelting is a proven technology that reclaims lead from lead-acid battery waste sites. The Concurrent Technologies and Exide Corporation (Exide) have demonstrated the use of secondary lead smelting to reclaim usable lead from various types of waste materials from Superfund and other lead-containing sites. Reclamation of lead is based on existing lead smelting procedures and basic pyrometallurgy.

The figure below is a generalized process flow diagram. Waste material is first excavated from Superfund sites or collected from other sources. The waste is then preprocessed to reduce particle size and to remove rocks, soil, and other debris. Next, the waste is transported to the smelter.

At the smelter, waste is fed to reverberatory or blast furnaces, depending on particle size or lead content. The two reverberatory furnaces normally treat lead from waste lead-acid batteries, as well as other lead-containing material. The furnaces are periodically tapped to remove slag, which contains 60 to 70 percent lead, and a soft pure lead product.

The two blast furnaces treat slag generated from the reverberatory furnaces, as well as larger-

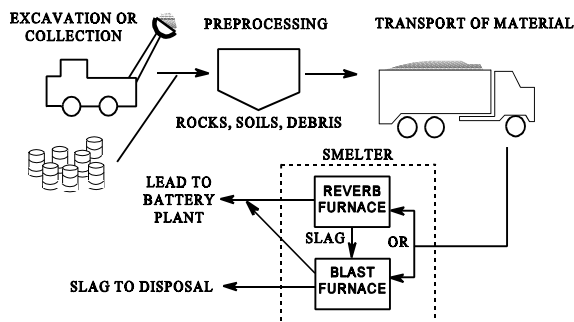
sized lead-containing waste. These furnaces are tapped continuously for lead and tapped intermittently to remove slag, which is transported offsite for disposal. The reverberatory and blast furnace combination at Exide can reclaim lead from batteries and waste with greater than 99 percent efficiency.

WASTE APPLICABILITY:

The process has been demonstrated to reclaim lead from a variety of solid materials, including rubber battery case material, lead dross, iron shot abrasive blasting material, and wood from demolition of houses coated with lead paint. The technology is applicable to solid wastes containing more than 2 percent lead, provided that they do not contain excessive amounts of calcium, silica, aluminum, or other similar constituents. Explosive and flammable liquids cannot be processed in the furnace. As tested, this technology is not applicable to soil remediation.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Field work for the project was completed in February 1993.



Smelting Lead-Containing Waste Process

The process was tested at three Superfund sites. Materials obtained from two additional sites were also used for these tests. Results from the Emerging Technology Program, presented in the table below, show that the process is applicable to waste materials at each site and economically feasible for all but demolition material. The Emerging Technology Bulletin (EPA/540/F-94/510), the Emerging Technology Summary (EPA/540/SR-95/504), and the Emerging Technology Report (EPA/540/R-95/504) are available from EPA. An article about the technology was also published by the *Journal of Hazardous Materials* in February 1995.

Specific technical problems encountered included (1) loss of furnace production due to material buildup within the furnaces, (2) breakdowns in the feed system due to mechanical overloads, and (3) increased oxygen demands inside the furnaces. All of these problems were solved by adjusting material feed rates or furnace parameters. Based on these tests, Concurrent Technologies has concluded that secondary lead

smelting is an economical method of reclaiming lead from lead-containing waste material collected at Superfund sites and other sources.

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Source of Material/ Type of Material Tested	% Lead	Economical*	Test Results
Tonolli Superfund site (PA)/ Battery cases	3 to 7	Yes	Lead can be reclaimed in secondary lead smelter; incorporated into regular blast furnace feed stock.
Hebalka Superfund site (PA)/ Battery cases	10	Yes	Lead can be reclaimed in secondary lead smelter; reduced in size and incorporated into regular reverberatory furnace feed stock.
Pedricktown Superfund site (NJ)/ Battery cases; lead dross, residue, and debris	45	Yes	Lead can be reclaimed in secondary lead smelter; screened and incorporated into regular reverberatory and blast furnace feed stocks.
Laurel House Women's Shelter (PA)/ Demolition material contaminated with lead-based paint.	1	No	Lead can be reclaimed in secondary lead smelter; however, the cost of processing the material was estimated to be very high.
PennDOT/ Abrasive bridge blasting material	3 to 5	Yes	Lead can be reclaimed in secondary lead smelter; incorporated into regular blast furnace feed stock.

* Compared to stabilization or landfilling

Results from Field Tests of the Smelting Lead-Containing Waste Technology

ENERGIA, INC. (Reductive Photo-Dechlorination Treatment)

TECHNOLOGY DESCRIPTION:

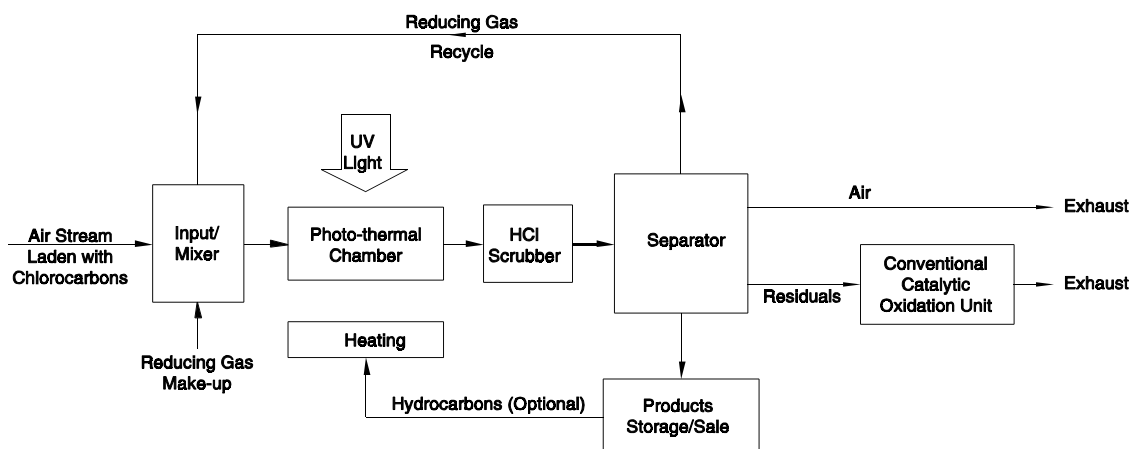
The Reductive Photo-Dechlorination (RPD) treatment uses ultraviolet (UV) light in a reducing atmosphere and at moderate temperatures to treat waste streams containing chlorinated hydrocarbons (CIHC). Because CIHCs are destroyed in a reducing environment, the only products are hydrocarbons and hydrogen chloride (HCl).

The RPD process is depicted in the figure below. The process consists of five main units: (1) input/mixer (2) photo-thermal chamber (3) HCl scrubber (4) separator and (5) products storage and recycling. Chlorinated wastes may be introduced into the process in one of three ways: vapor, liquid, or bound to an adsorbent, such as activated carbon.

Air laden with chlorocarbon vapors is first passed through a condenser, which removes chlorinated materials as liquids. Chlorocarbon liquids are fed into a vaporizer, mixed with a reducing gas, and passed into the photo-thermal chamber.

Chlorinated contaminants adsorbed onto activated carbon are purged with reducing gas and mildly heated to induce vaporization. The ensuing vapors are then fed into the photo-thermal chamber.

The photo-thermal chamber is the heart of the RPD process because all reactions central to the process occur in this chamber. Saturated, olefinic, or aromatic chlorocarbons with one or more carbon-chlorine bonds are exposed to UV light, heat, and a reducing atmosphere, such as hydrogen gas or methane. According to ENERGIA, Inc., carbon-chlorine bonds are broken, resulting in chain-propagating hydrocarbon reactions. Chlorine atoms are eventually stabilized as HCl, which is easily removed in a scrubber. Hydrocarbons may hold their original structures, rearrange, cleave, couple, or go through additional hydrogenation. Hydrocarbons produced from the dechlorination of wastes include ethane, acetylene, ethene, and methane. Valuable hydrocarbon products can be stored, sold, or recycled as auxiliary fuel to heat the photo-thermal chamber.



Reductive Photo-Dechlorination (RPD) Treatment

WASTE APPLICABILITY:

The RPD process is designed specifically to treat volatile chlorinated wastes in the liquid, gaseous, or adsorbed states. The RPD process was tested on methyl chloride, dichloromethane (DCM), chloroform, carbon tetrachloride, trichloroethane (TCA), dichloroethene (PCE), and trichloroethene (TCE).

Field applications include treatment of organic wastes discharged from soil vapor extraction operations, vented from industrial hoods and stacks, and adsorbed on activated carbon. The process can be used to (1) treat gas streams containing chlorinated hydrocarbons, and (2) pretreat gas streams entering catalytic oxidation systems by reducing chlorine content and protecting the catalyst against poisoning.

In comparison to other photo-thermal processes (such as reductive photo-thermal oxidation [RPTO] and photo-thermal oxidation [PTO]), the RPD process is mostly applicable to streams without air and very high concentrations of contaminants (bulk down to greater than 1 percent). At very low concentrations (parts per million) and in the presence of air, the other photo-thermal processes may more cos- effective.

STATUS:

Bench-scale experiments were conducted on several contaminants (such as DCM, DCE, TCA, and TCE). Measurements of concentrations of parent compounds and products as a function of residence time were obtained at several test conditions. From these measurements, conversion and dechlorination efficiencies were determined at optimal operating conditions.

Experimental results on a representative chlorocarbon contaminant (TCA) are available in the Emerging Technology Bulletin (EPA/540/F-94/508). Greater than 99 percent conversion and

dechlorination were demonstrated with high selectivity towards two saleable hydrocarbon products, ethane and methane. Similar favorable results were obtained for other saturated and unsaturated chlorocarbons treated by the RPD process.

Results of a cost analysis based on experimental data indicate that the RPD process is extremely cost competitive. For example, the cost of treating TCE concentrations of 1,000 ppm and 10,000 ppm is \$1.10 and \$0.25 per pound treated, respectively. The cost per 1,000 cubic feet of contaminated stream with 1,000 ppm is \$0.38 and \$0.88, respectively.

All technical data have been gathered and optimization has been completed. Design and assembly of a pilot-scale prototype are underway. The field demonstration may take place during 1999. The developer is seeking appropriate sites for field demonstration. After successful demonstration, the RPD process will be ready for full-scale commercialization.

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ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION

(Hybrid Fluidized Bed System)

TECHNOLOGY DESCRIPTION:

The Hybrid Fluidized Bed (HFB) system treats contaminated solids and sludges by incinerating organic compounds and extracting and detoxifying volatile metals. The system consists of three stages: a spouted bed, a fluidized afterburner, and a high-temperature particulate soil extraction system.

First, the spouted bed rapidly heats solids and sludges to allow extraction of volatile organic and inorganic compounds. The spouted bed retains larger soil clumps until they are reduced in size but allows fine material to pass through quickly. This segregation process is beneficial because organic contaminants in fine particles vaporize rapidly. The decontamination time for large particles is longer due to heat and mass transfer limitations.

The central spouting region is operated with an inlet gas velocity of greater than 150 feet per second. This velocity creates an abrasion and grinding action, rapidly reducing the size of the feed materials through attrition. The spouted bed operates between 1,500 and 1,700 °F under oxidizing conditions.

Organic vapors, volatile metals, and fine soil particles are carried from the spouted bed through an open-hole type distributor, which forms the bottom of the second stage, the

fluidized bed afterburner. The afterburner provides sufficient retention time and mixing to incinerate the organic compounds that escape the spouted bed, resulting in a destruction and removal efficiency of greater than 99.99 percent. The afterburner also contains bed materials that absorb metal vapors, capture fine particles, and promote formation of insoluble metal silicates. The bed materials are typically made of silica-supported bauxite, kaolinite, or lime.

In the third stage, the high-temperature particulate soil extraction system removes clean processed soil from the effluent gas stream with one or two hot cyclones. Clean soil is extracted hot to prevent unreacted volatile metal species from condensing in the soil. Off-gases are then quenched and passed through a conventional baghouse to capture the condensed metal vapors.

Generally, material handling problems create major operational difficulties for soil cleanup devices. The HFB system uses a specially designed auger feed system. Solids and sludges are dropped through a lock hopper system into an auger shredder, which is a rugged, low-revolutions-per-minute, feeding-grinding device. Standard augers are simple and reliable, but often they are susceptible to clogging from feed compression in the auger. In the HFB system, the auger shredder is close-coupled to the spouted bed to reduce compression and clump formation during feeding. The close-couple

arrangement locates the tip of the auger screw several inches from the internal surface of the spouted bed, preventing the formation of soil plugs.

WASTE APPLICABILITY:

This technology is applicable to soils and sludges contaminated with organic and volatile inorganic contaminants. Nonvolatile inorganics are not affected.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in January 1990. Design and construction of the commercial prototype HFB system and a limited shakedown are complete. The Emerging Technology Bulletin (EPA/540/F-93/508) is available from EPA.

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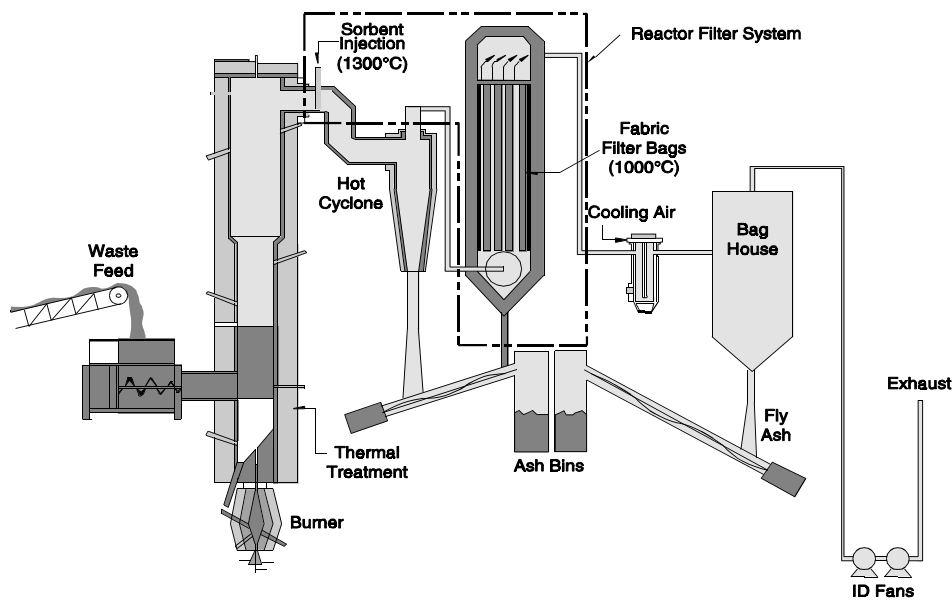
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ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION (Reactor Filter System)

TECHNOLOGY DESCRIPTION:

The Energy and Environmental Research Corporation (EER) Reactor Filter System (RFS) technology is designed to control gaseous and entrained particulate matter emissions from the primary thermal treatment of sludges, soils, and sediments. Most Superfund sites are contaminated with toxic organic chemicals and metals. Currently available thermal treatment systems for detoxifying these materials release products of incomplete combustion (PIC) and volatile toxic metals. In addition, the large air pollution control devices (APCD) often required to control PICs and metals are generally not suitable for transport to remote Superfund sites. EER designed the RFS to avoid some of these logistical problems. The RFS uses a fabric filter installed immediately downstream of the thermal treatment process; the filter controls toxic metals, particulates, and unburned organic species. The RFS involves the following three steps:

- First, solids are treated with a primary thermal process, such as a rotary kiln, fluidized bed, or other system designed for thermal treatment.
- Next, a low-cost, aluminosilicate sorbent, such as kaolinite, is injected into the flue gases at temperatures near 1,300 °C (2,370 °F). The sorbent reacts with volatile metal species such as lead, cadmium, and arsenic in the gas stream; the metals chemically adsorb onto the surfaces of the sorbent particles. This adsorption forms insoluble, nonleachable aluminosilicate complexes similar to cementitious species.
- Finally, fabric filtration, operating at temperatures up to 1,000 °C (1,830 °F) provides additional residence time for the sorbent/metal reaction, producing nonleachable by-products. This step also provides additional time for the destruction of organic compounds associated with particulate matter, reducing ash toxicity.



Example Application of RFS Equipment

Because of the established link between PIC formation and gas-particle chemistry, this process can virtually eliminate potential polychlorinated dioxin formation.

The RFS may improve the performance of existing thermal treatment systems for Superfund wastes containing metals and organics. During incineration, hazardous organics are often attached to the particulate matter that escapes burning in the primary zone. The RFS provides sufficient residence time at sufficiently high temperatures to destroy such organics. Also, by increasing gas-solid contact parameters, the system can decrease metal emissions by preventing the release of metals in vapors or retained on entrained particles.

The figure on the previous page shows the RFS installed immediately downstream of the primary thermal treatment zone at EER's Spouted Bed Combustion Facility. Because the spouted bed generates a highly particulate-laden gas stream, a high-temperature cyclone is used to remove coarse particulate matter upstream of the RFS. Sorbent is injected into the flue gas upstream of the high temperature fabric filter. A conventional baghouse was available for comparison with RFS performance during the demonstration. However, the baghouse is not needed in typical RFS applications because the high-temperature filtration medium has shown similar performance to conventional fabric filtration media.

WASTE APPLICABILITY:

The RFS is designed to remove entrained particulates, volatile toxic metals, and condensed-phase organics present in high-temperature (800 to 1,000 °C) gas streams generated from the thermal treatment of contaminated soils, sludges, and sediments. Many conventional treatments can be combined with the RFS technology. Process residuals will consist of nonleachable particulates that are essentially free of organic compounds, thus reducing toxicity, handling risks, and landfill disposal.

STATUS:

The RFS was accepted into the Emerging Technology Program in 1993. EER developed the pilot-scale process through a series of bench-scale screening studies, which were completed in September 1994. The screening studies guided the sorbent selection and operating conditions for the pilot-scale demonstration. The tests were completed in 1996; the final report will be available from the National Technical Information Service.

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ENVIRONMENTAL BIOTECHNOLOGIES, INC. (Fungal Degradation Process)

TECHNOLOGY DESCRIPTION:

Polycyclic aromatic hydrocarbons (PAH) are typical pollutants at creosote wood treatment sites and at manufacturing gas plants (MGP). Media contaminated with these compounds are considered hazardous due to the potential carcinogenic effects of specific PAHs.

Environmental BioTechnologies, Inc. (EBT), investigated the bioremediation of contaminants associated with former MGP sites in a program cosponsored by the Electric Power Research Institute and the U. S. EPA. Initially, EBT screened over 500 fungal cultures (mostly brown and white rot fungi) for their ability to degrade PAHs and other organic pollutants. A group of 30 cultures were more intensely examined and several cultures were optimized for use in a soil composting process.

EBT conducted bench-scale treatability studies to assess the feasibility of PAH degradation in soil using a fungal-augmented system designed to enhance natural biological metabolic processes. Results of one study are shown in the figure below. Concentrations of 10 PAHs were determined over a 59-day treatment period.

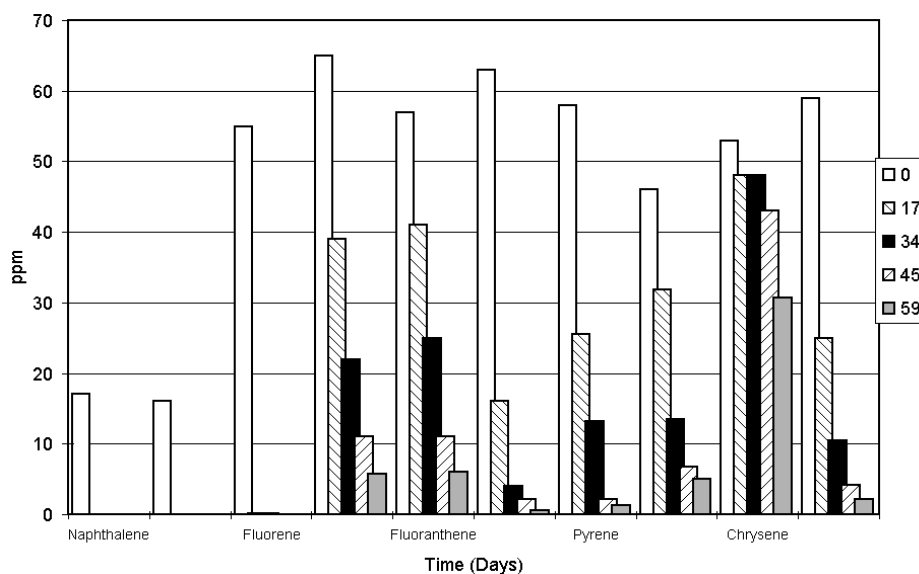
Some states have a soil treatment standard of 100 parts per million for total PAHs. EBT's fungal treatment process was able to reach this cleanup standard within a 5- to 6-week treatment period for one PAH-contaminated soil, as shown in the figure on the next page.

WASTE APPLICABILITY:

One intended environmental application for this technology is the treatment of soil and sediment contaminated with coal tar wastes from former MGP sites. Soils at these sites are contaminated with PAHs and are difficult to cost-effectively remediate. EBT's fungal soil treatment process is projected to cost \$66 to \$80 per ton, which is more cost-effective than other technical approaches such as coburning in utility burners, thermal desorption, and incineration.

STATUS:

EBT was accepted into the SITE Emerging Technology Program in 1993 and began laboratory studies in 1994. The project was completed in 1996. The overall project objectives were to (1) identify fungal and bacterial cultures that efficiently degrade coal tar



Fungal Degradation of Five PAHs in Soil Over A 59-Day Period

wastes, and (2) develop and demonstrate a pilot-scale process that can be commercialized for utility industry applications.

EBT initially worked with PAH-spiked water and soils. EBT then tested, under optimized conditions, selected soil cultures from several MGP sites identified by New England Electric Services, a utility company sponsor. Testing identified several possibly superior fungal cultures capable of degrading PAHs. These cultures exhibited degradative preferences for either lower molecular weight or higher molecular weight PAHs, suggesting a consortia as a possible best approach. These cultures were then examined in nutrient-supplemented systems to determine optimal PAH degradation rates.

A bench-scale composter system was used to determine optimal moisture content, soil amendment requirements, and inoculation procedures for accelerating PAH degradation. During the second year, small (less than 1 cubic yard) plots of MGP-site soil were used to test the optimized process in laboratory studies before a field demonstration is conducted. Results from the evaluation was published by U. S. EPA in 1997. Based on its performance during the Emerging Technology Program evaluation, the microbial composting process has been invited to participate in the SITE Demonstration Program.

EBT has also conducted a bench-scale treatability study for a company in France to determine the feasibility of fungal PAH degradation in MGP soil. Results demonstrated an increased rate of biodegradation in the fungal-augmented system for all of the measured individual PAH compounds in the 80-day treatment period, compared with the natural, unamended system.

EBT is also currently conducting a 10-ton soil PAH field project to demonstrate that the fungal degradation process can be scaled up and used in commercial applications.

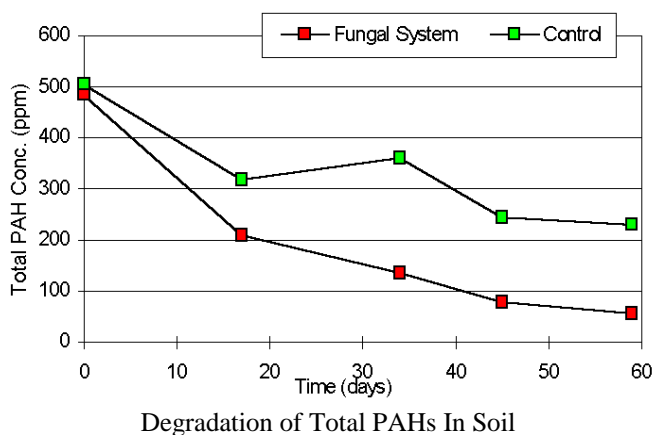
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FERRO CORPORATION

(Waste Vitrification Through Electric Melting)

TECHNOLOGY DESCRIPTION:

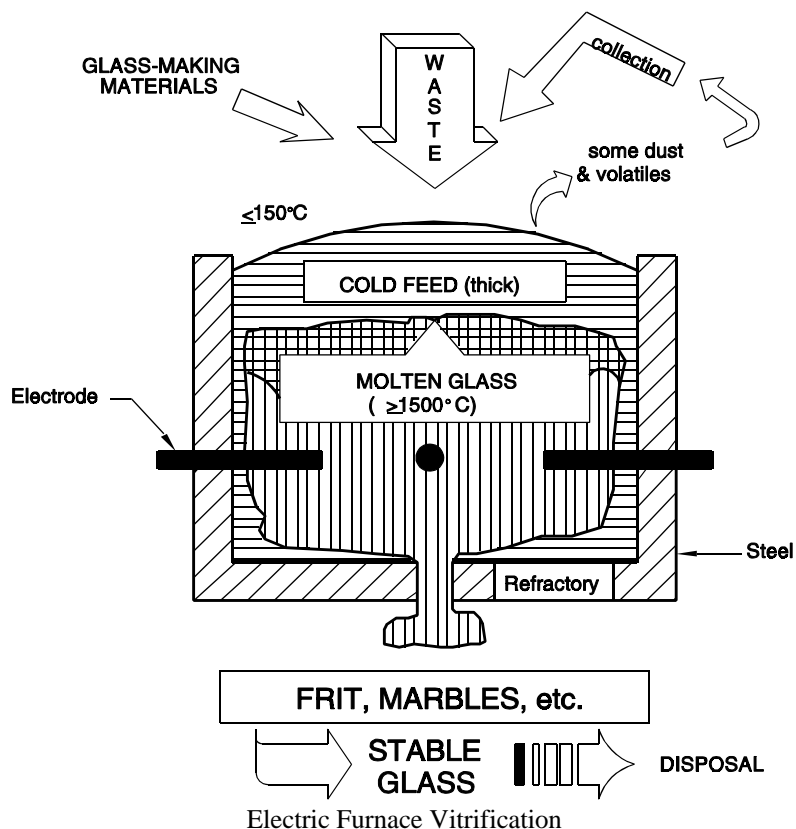
Vitrification technology converts contaminated soils, sediments, and sludges into oxide glasses, chemically rendering them nontoxic and suitable for landfilling as nonhazardous materials. Successful vitrification of soils, sediments, and sludges requires (1) development of glass compositions tailored to a specific waste, and (2) glass melting technology that can convert the waste and additives into a stable glass without producing toxic emissions.

In an electric melter, glass — an ionic conductor of relatively high electrical resistivity — stays molten with heating. Such melters process waste under a relatively thick blanket of feed material, which forms a counterflow scrubber that limits volatile emissions (see figure below).

Commercial electric melters have significantly reduced the loss of inorganic volatile constituents such as boric anhydride (B_2O_3) or lead oxide (PbO). Because of its low emission rate and small volume of exhaust gases, electric melting is a promising technology for incorporating waste into a stable glass matrix.

WASTE APPLICABILITY:

Vitrification stabilizes inorganic components found in hazardous waste. In addition, the high temperature involved in glass production (about $1,500^\circ C$) decomposes organic compounds in the waste such as anthracene, bis(2-ethylhexyl phthalate), and pentachlorophenol. The decomposition products can easily be removed from the low volume of melter off-gas.



STATUS:

Under the Emerging Technology Program, synthetic soil matrix IV (SSM-IV) has been developed and subjected to toxicity characteristic leaching procedure (TCLP) testing.

Ten independent replicates of the preferred composition produced the following results:

TCLP analyte concentration, parts per million		
Metal	Remediation Limit	Mean of Glass Replicates
As	5	<0.100
Cd	1	<0.010
Cr	5	0.019
Cu	5	0.355
Pb	5	0.130
Ni	5	<0.010
Zn	5	0.293

SSM-IV and additives (including sand, soda ash, and other minerals) required to convert SSM-IV to the preferred glass composition have been processed in a laboratory-scale electric melter. Three separate campaigns have produced glass at 17 pounds per hour at a fill of 67 percent SSM-IV and 33 percent glass-making additives. The TCLP mean analyte concentrations were less than 10 percent of the remediation limit at a statistical confidence of 95 percent. Ferro Corporation's experience indicates that this melting rate would produce an equivalent rate of 1 ton per hour in an electric melter used to treat wastes at a Superfund site. The Emerging Technology Bulletin (EPA/540/F-95/503) is available from EPA.

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GENERAL ATOMICS, NUCLEAR REMEDIATION TECHNOLOGIES DIVISION (Acoustic Barrier Particulate Separator)

TECHNOLOGY DESCRIPTION:

The acoustic barrier separates particulates in a high temperature gas flow. The separator produces an acoustic waveform directed against the gas flow, causing particulates to move opposite the flow. The particulates drift to the wall of the separator, where they aggregate with other particulates and precipitate into a collection hopper. The acoustic barrier particulate separator differs from other separators by combining both high efficiency and high temperature capabilities.

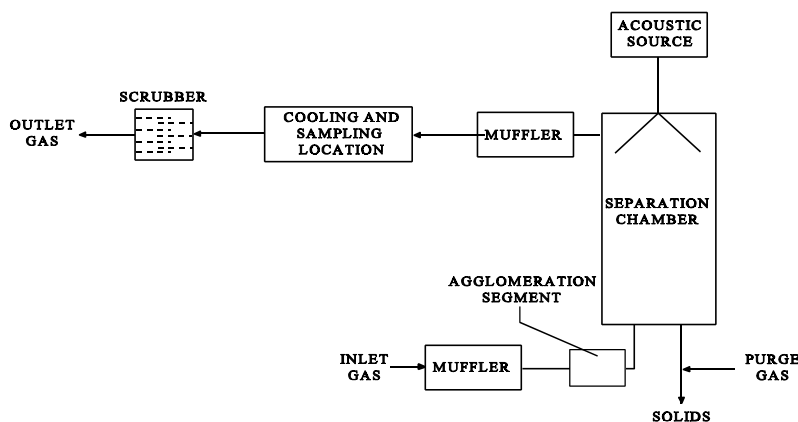
The figure below presents a conceptual design. High temperature inlet gas flows through a muffler chamber and an agglomeration segment before entering the separation chamber. In the separation chamber, particulates stagnate due to the acoustic force and then drift to the chamber wall, where they collect as a dust cake that falls into a collection hopper. The solids are transported from the collection hopper by a screw-type conveyor against a clean purge gas counterflow. The purge gas cools the solids and guards against contamination of particulates by inlet-gas volatiles in the process stream.

The gas flows past the acoustic source and leaves the separation chamber through an exit port. The gas then passes through another muffler chamber and flows through sections where it is allowed to cool and any remaining gas-borne particulate samples are collected. Finally, the gas is further scrubbed or filtered as necessary before it is discharged.

The separator can remove the entire range of particle sizes; it has a removal efficiency of greater than 90 percent for submicron particles and an overall removal efficiency of greater than 99 percent. Due to the large diameter of the separator, the system is not prone to fouling.

WASTE APPLICABILITY:

This technology can treat off-gas streams from thermal desorption, pyrolysis, and incineration of soil, sediment, sludges, other solid wastes, and liquid wastes. The acoustic barrier particulate separator is a high-temperature, high-throughput process with a high removal efficiency for fine dust and fly ash. It is particularly suited for thermal processes where high temperatures must be maintained to prevent condensation onto particulates. Applications include removal of



Acoustic Barrier Particulate Separator

gas-borne solids during thermal treatment of semivolatile organics, such as polychlorinated biphenyls, and gas-phase separation of radioactive particles from condensable hazardous materials.

STATUS:

The acoustic barrier particulate separator was accepted into the SITE Emerging Technology Program in 1993. The principal objective of this project will be to design, construct, and test a pilot-scale acoustic barrier particulate separator that is suitable for parallel arrangement into larger systems. The separator will be designed for a flow of 300 cubic feet per minute and will be tested using a simulated flue gas composed of heated gas and injected dust.

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HARDING LAWSON ASSOCIATES (Formerly ABB Environmental Services, Inc.) (Two-Zone, Plume Interception, In Situ Treatment Strategy)

TECHNOLOGY DESCRIPTION:

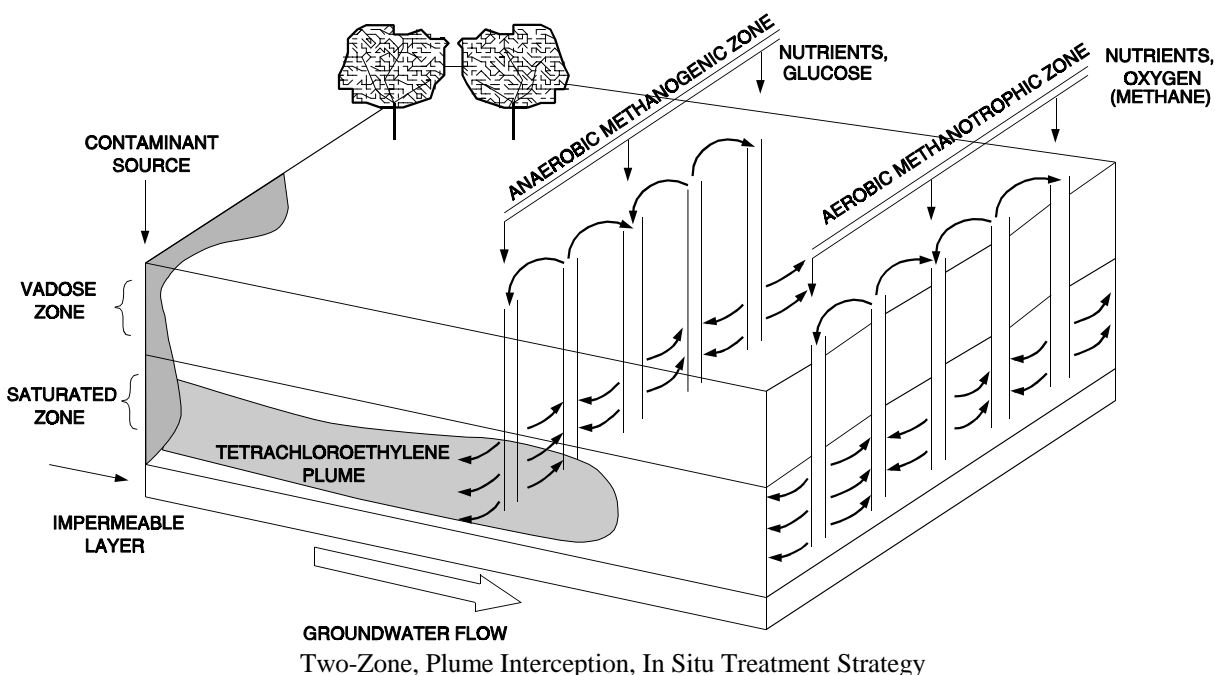
The two-zone, plume interception, in situ treatment strategy is designed to treat chlorinated and nonchlorinated organic compounds in saturated soils and groundwater using a sequence of anaerobic and aerobic conditions (see figure below). The in situ anaerobic and aerobic system constitutes a treatment train that biodegrades a wide assortment of chlorinated and nonchlorinated compounds.

When applying this technology, anaerobic and aerobic conditions are produced in two distinct, hydraulically controlled, saturated soil zones. Groundwater passes through each zone as it is recirculated through the treatment area. The first zone, the anaerobic zone, is designed to partially dechlorinate highly chlorinated solvents such as tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane with natural biological processes. The second zone, the aerobic zone, is

designed to biologically oxidize the partially dechlorinated products from the first zone, as well as other compounds that were not susceptible to the anaerobic treatment phase.

Anaerobic conditions are produced or enhanced in the first treatment zone by introducing a primary carbon source, such as lactic acid, and mineral nutrients, such as nitrogen and phosphorus. When proper anaerobic conditions are attained, the target contaminants are reduced. For example, PCE is dechlorinated to TCE, and TCE is dechlorinated to dichloroethene (DCE) and vinyl chloride. Under favorable conditions, this process can completely dechlorinate the organics to ethene and ethane.

Aerobic conditions are produced or enhanced in the second treatment zone by introducing oxygen, mineral nutrients such as nitrogen and phosphorus, and possibly an additional carbon source, such as methane (if an insufficient supply



of methane results from the upstream, anaerobic zone). When proper aerobic conditions are attained in this zone, partially dechlorinated products and other target compounds from the first zone are oxidized. For example, less-chlorinated ethenes such as DCE and vinyl chloride are cometabolized during the aerobic microbiological degradation of methane.

The treatment strategy is designed to biologically remediate subsoils by enhancing indigenous microorganism activity. If indigenous bacterial populations do not provide the adequate anaerobic or aerobic results, specially adapted cultures can be introduced to the aquifer. These cultures are introduced using media-filled trenches that can support added microbial growth.

WASTE APPLICABILITY:

The two-zone, plume interception, in situ treatment strategy is designed to treat groundwater and saturated soils containing chlorinated and nonchlorinated organic compounds.

STATUS:

The two-zone, plume interception, in situ treatment strategy was accepted into the SITE Emerging Technology Program in July 1989. Optimal treatment parameters for field testing were investigated in bench-scale soil aquifer simulators. The objectives of bench-scale testing were to (1) determine factors affecting the development of each zone, (2) evaluate indigenous bacterial communities, (3) demonstrate treatment of chlorinated and nonchlorinated solvent mixtures, and (4) develop a model for the field remediation design. The

Emerging Technology Bulletin (EPA/540/F-95/510), which details the bench-scale testing results, is available from EPA.

A pilot-scale field demonstration system was installed at an industrial facility in Massachusetts. Pilot-scale testing began in September 1996. Results from this testing indicate the following:

- The reductive dechlorination of PCE and TCE to DCE, VC, and ethene has been accomplished primarily by sulfate-reducing bacteria.
- A time lag of about 4 months was required before significant reductive dechlorination occurred. This corresponded to the time and lactic acid dosing required to reduce the redox to about -100 throughout the treatment cell.
- Sequential anaerobic-aerobic (Two-Zone) biodegradation of PCE and its degradation products appear to be a viable and cost-effective treatment technology for the enhancement of natural reductive dechlorination processes.

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HAZARDOUS SUBSTANCE MANAGEMENT RESEARCH CENTER AT NEW JERSEY INSTITUTE OF TECHNOLOGY and RUTGERS, THE STATE UNIVERSITY OF NEW JERSEY (Pneumatic Fracturing and Bioremediation Process)

TECHNOLOGY DESCRIPTION:

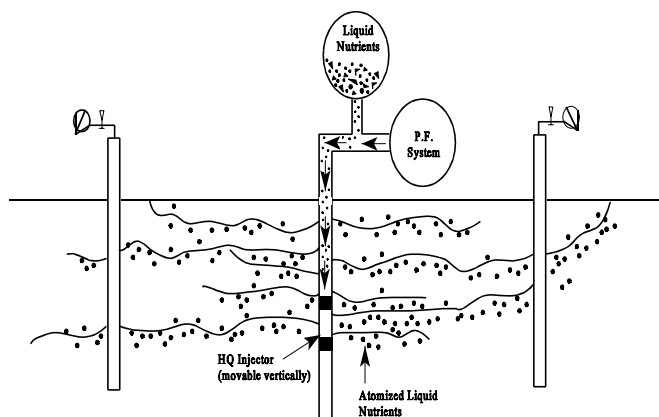
The Hazardous Substance Management Research Center (HSMRC) has developed a technology for the in situ remediation of organic contaminants. The process enhances in situ bioremediation through pneumatic fracturing to establish an extended biodegradation zone supporting aerobic, denitrifying, and methanogenic populations. The technique is designed to provide faster transport of nutrients and electron acceptors (for example, oxygen and nitrate) to the microorganisms, particularly in geologic formations with moderate to low permeability.

An overview of the process is shown in the figure below. First, the formation is pneumatically fractured by applying high pressure air in 2-foot-long, discrete intervals through a proprietary device known as an HQ Injector. After the formation has been fractured with air, nutrients or other chemicals are introduced into the fracture network to stimulate biological activity. The carrier gas and the particular amendments

(atomized liquid or dry media) injected into the formation can be adjusted according to the target contaminant and the desired degradation environment (aerobic, denitrifying, and anaerobic). The high air-to-liquid ratio atomizes the liquid supplements during injection, increasing their ability to penetrate the fractured formation. In the final step of the process, the site is operated as an in situ bioremediation cell to degrade the contaminants. A continuous, low-level air flow is maintained through the fracture network by a vacuum pump that provide oxygen to the microbial populations. Periodically, additional injections are made to replenish nutrients and electron acceptors.

WASTE APPLICABILITY:

The integrated process can be applied to a wide variety of geologic formations. In geologic formations with low to moderate permeabilities, such as those containing clay, silt, or tight bedrock, the process creates artificial fractures that increase formation permeability. In



Overview of the Integrated Pneumatic Fracturing and Bioremediation Process

formations with higher permeabilities, the process is still useful for rapid aeration and delivery of amendments to the microorganisms.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991 and was evaluated at a gasoline refinery located in the Delaware Valley. Soil at the site was contaminated with benzene, toluene, and xylene (BTX) at concentrations up to 1,500 milligrams per kilogram, along with other hydrocarbons. The evaluation was completed in May 1994. Contact the EPA Project Manager for a copy of the results from the evaluation. A journal article has been submitted to the *Journal of Air and Waste Management*. Throughout the 50-week pilot-scale evaluation, off-gases were monitored for BTX, carbon dioxide, and methane, which served as indicators of biological activity. Process effectiveness was evaluated by comparing analytical results of soil samples collected at the beginning and the end of the evaluation.

Vapor extraction tests revealed postfracture air flows to be 24 to 105 times higher than prefracture air flows. Measurements of ground surface heave and observations of fractures venting to the ground surface indicated that the fractures had effective radii of up to 20 feet from the injection point.

Soil gas data collected at the monitoring wells show that the indigenous microbial populations responded favorably to the injection of the soil amendments. Soil gas data consistently showed elevated levels of carbon dioxide immediately following each injection, indicating increased rates of BTX mineralization. Correspondingly, BTX concentrations in the wells gradually declined over time after depletion of oxygen and nitrate, at which time methanogenic processes began to dominate until the next subsurface amendment injection.

Comparative analysis of soil samples extracted from the site before and after the evaluation period showed that a substantial amount of BTX was degraded as a result of the integrated process. Total soil-phase BTX was reduced from 28 to 6 kilograms over the 50-week pilot test, corresponding to a 79 percent reduction in total BTX mass. An assessment of pathways of BTX loss from the formation showed a large proportion of the mass reduction (85 percent) was attributable to bioremediation.

Process development for this evaluation was supported in part by the U.S. Department of Defense, Advanced Research Projects Agency, and the Office of Naval Research.

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HIGH VOLTAGE ENVIRONMENTAL APPLICATIONS, INC. (High-Energy Electron Beam Irradiation)

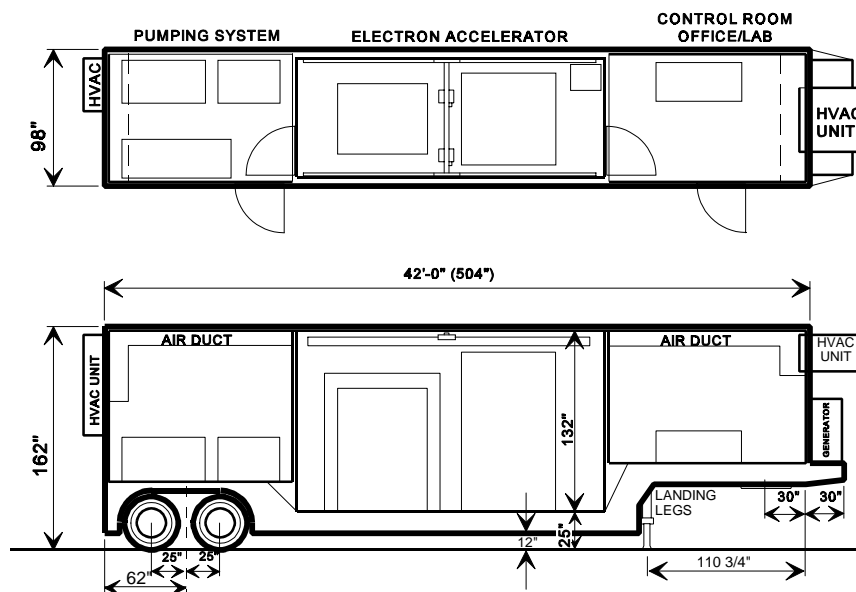
TECHNOLOGY DESCRIPTION:

The high-energy electron beam irradiation technology is a low-temperature method for destroying complex mixtures of hazardous organic chemicals in hazardous wastes. These wastes include slurried soils, river or harbor sediments, and sludges. The technology can also treat contaminated soils and groundwater.

The figure below illustrates the mobile electron beam treatment system. The system consists of a computer-automated, portable electron beam accelerator and a delivery system. The 500-kilovolt electron accelerator produces a continuously variable beam current from 0 to 40 milliamperes. At full power, the system is rated at 20 kilowatts. The waste feed rate and beam current can be varied to obtain doses of up to 2,000 kilorads in a one-pass, flow-through mode.

The system is trailer-mounted and is completely self-contained, including a 100-kilowatt generator for remote locations or line connectors where power is available. The system requires only a mixing tank to slurry the treatable solids. The system also includes all necessary safety checks.

The computerized control system continuously monitors the waste feed rate, absorbed dose, accelerator potential, beam current, and all safety shutdown features. The feed rate is monitored with a calibrated flow valve. The absorbed dose is estimated based on the difference in the temperature of the waste stream before and after irradiation. The system is equipped with monitoring devices that measure the waste stream temperature before and after irradiation. Both the accelerating potential and the beam current are obtained directly from the transformer.



Mobile Electron Beam Treatment System

Except for slurring, this technology does not require any pretreatment of wastes.

WASTE APPLICABILITY:

This technology treats a variety of organic compounds, including wood-treating chemicals, pesticides, insecticides, petroleum residues, and polychlorinated biphenyls (PCB) in slurried soils, sediments, and sludges.

STATUS:

High Voltage Environmental Applications, Inc. (HVEA), was accepted into the SITE Emerging Technology Program in 1993. Under this program, HVEA will demonstrate its mobile pilot plant on soils, sediments, or sludges at various hazardous waste sites. Candidate sites are being identified. On-site studies will last up to 2 months.

Initial studies by HVEA have shown that electron beam irradiation effectively removes 2,4,6-trinitrotoluene from soil slurries.

As part of the Emerging Technology Program, HVEA has identified 350 tons of soil contaminated with an average Aroclor 1260 concentration of about 1,000 milligrams per kilogram. A small 1-ton feasibility study was conducted in August 1995. After results are available from the 1-ton study, HVEA plans to make its mobile unit available for full-scale remediations.

In a recent bench-scale study, a multisource hazardous waste leachate containing 1 percent dense nonaqueous phase liquid was successfully treated. In another bench-scale study, a leachate containing a light nonaqueous phase liquid contaminated with PCBs was treated to F039 standards.

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INSTITUTE OF GAS TECHNOLOGY (Chemical and Biological Treatment)

TECHNOLOGY DESCRIPTION:

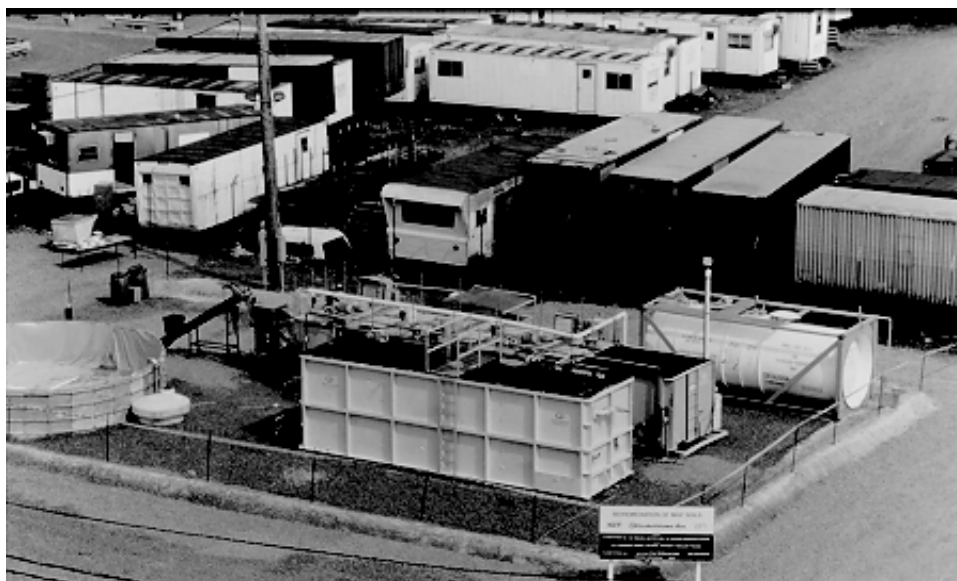
The Institute of Gas Technology (IGT) chemical and biological treatment (CBT) process remediates sludges, soils, groundwater, and surface water contaminated with organic pollutants, such as polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls. The treatment system (see photograph below) combines two remedial techniques: (1) chemical oxidation as pretreatment, and (2) biological treatment using aerobic and anaerobic biosystems in sequence or alone, depending on the waste. The CBT process uses mild chemical treatment to produce intermediates that are biologically degraded, reducing the cost and risk associated with a more severe treatment process such as incineration.

During the pretreatment stage, the contaminated material is treated with a chemical reagent that degrades the organics to carbon dioxide, water,

and partially oxidized intermediates. In the second stage of the CBT process, biological systems degrade the hazardous residual materials and the partially oxidized intermediates from the first stage. Chemically treated wastes are subjected to cycles of aerobic and anaerobic degradation, if aerobic or anaerobic treatment alone is not sufficient. Several cycles of chemical and biological treatment are also used for extremely recalcitrant contaminants.

WASTE APPLICABILITY:

The CBT process can be applied to soils, sludges, groundwater, and surface water containing (1) high waste concentrations that would typically inhibit bioremediation, or (2) low waste concentrations for which bioremediation alone is too slow. The process is not adversely affected by radionuclides or heavy metals. Depending on the types of heavy metals present, these metals will bioaccumulate in the biomass,



Chemical and Biological Treatment Process

complex with organic or inorganic material in the soil slurries, or become soluble in the recycled water.

The CBT process can be applied to a wide range of organic pollutants, including alkenes, chlorinated alkenes, aromatics, substituted aromatics, and complex aromatics.

STATUS:

IGT evaluated the CBT process for 2 years under the SITE Emerging Technology Program. The Emerging Technology Bulletin (EPA/540/F-94/540), which details results from the evaluation, is available from EPA. Based on results from the Emerging Technology Program, this technology was invited to participate in the SITE Demonstration Program.

Under the SITE Demonstration Program, IGT plans to conduct a full-scale demonstration of the CBT process on sediments containing PAHs. Different operating scenarios will be used to demonstrate how effectively the CBT process treats sediments in a bioslurry reactor. Several sites are being considered for the demonstration.

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INSTITUTE OF GAS TECHNOLOGY (Fluid Extraction-Biological Degradation Process)

TECHNOLOGY DESCRIPTION:

The three-step, fluid extraction-biological degradation (FEBD) process removes organic contaminants from soil (see figure below). The process combines three distinct technologies: (1) fluid extraction, which removes the organics from contaminated solids; (2) separation, which transfers the pollutants from the extract to a biologically compatible solvent or activated carbon carrier; and (3) biological degradation, which destroys the pollutants and leaves innocuous end-products.

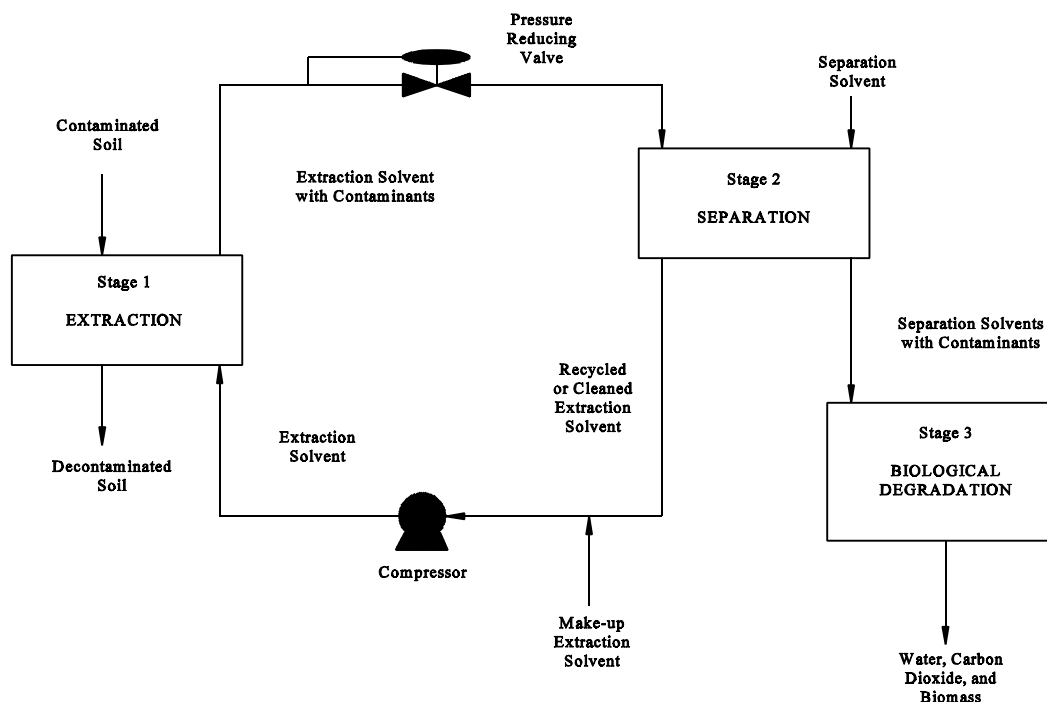
In the fluid extraction step, excavated soils are placed in a pressure vessel and extracted with a recirculated stream of supercritical or near-supercritical carbon dioxide. An extraction cosolvent may be added to enhance the removal of additional contaminants.

During separation, organic contaminants are transferred to a biologically compatible

separation solvent, such as water or a water-methanol mixture. The separation solvent is then sent to the final stage of the process, where bacteria degrade the waste to carbon dioxide and water. Clean extraction solvent is then recycled for use in the extraction stage.

Organic contaminants are biodegraded in aboveground aerobic bioreactors, using mixtures of bacterial cultures. Specific cultures are selected based on site contaminant characteristics. For example, if a site is primarily contaminated with polynuclear aromatic hydrocarbons (PAH), cultures able to metabolize or cometabolize these hydrocarbons are used. In this way the bioreactors can be configured to enhance the rate and extent of biodegradation.

Research continues on using bound, activated carbon in a carrier system during the separation step. Bound activated carbon should allow high-pressure conditions to be maintained in the fluid extraction step, resulting in enhanced extraction



Fluid Extraction-Biological Degradation Process

efficiency and decreased extraction time. Bound, activated carbon should also limit the loss of carbon dioxide, thereby decreasing costs. Activated carbon containing the bound PAHs could then be treated in the biodegradation step by converting the carrier system to a biofilm reactor. The activated carbon carrier systems could then be recycled into the high-pressure system of the extraction and separation steps.

WASTE APPLICABILITY:

This technology removes organic compounds from contaminated solids. It is more effective on some classes of organics, such as hydrocarbons (for example, gasoline and fuel oils), than on others, such as halogenated solvents and polychlorinated biphenyls. The process has also been effective in treating nonhalogenated aliphatic hydrocarbons and PAHs.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in June 1990. The Institute of Gas Technology has evaluated all three stages of the technology with soils from a Superfund site and from three other manufactured gas sites. These soils exhibited a variety of physical and chemical characteristics. About 85 to 99 percent of detectable PAHs, including two- to six-ring compounds, were removed from the soils.

The measurable PAHs were biologically converted in both batch-fed and continuously fed, constantly stirred, tank reactors. The conversion rate and removal efficiency were high in all systems. The PAHs were biologically removed or transformed at short hydraulic retention times. All PAHs, including four- to six-ring compounds, were susceptible to biological removal.

Results from this project were published in the *Emerging Technology Bulletin* (EPA/540/F-94/501), which is available from EPA. An article on the project was also submitted to the *Journal of Air and Waste Management*.

Potential users of the technology have expressed interest in continuing research, and the technology has been invited to participate in the SITE Demonstration Program. The technology would be able to remediate other manufactured gas sites, wood treatment sites, and contaminated soils and sediments.

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INSTITUTE OF GAS TECHNOLOGY **(Fluidized-Bed/Cyclonic Agglomerating Combustor)**

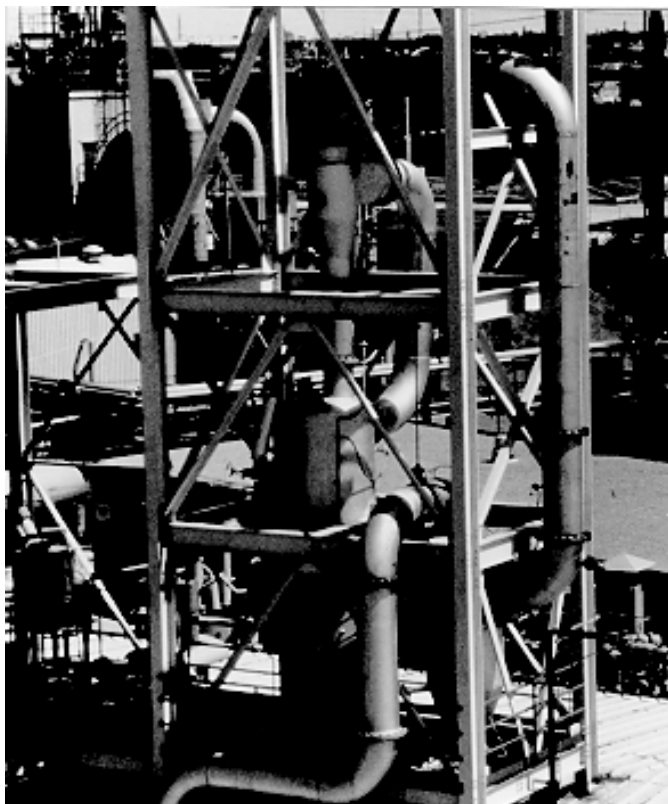
TECHNOLOGY DESCRIPTION:

The Institute of Gas Technology (IGT) has developed a two-stage, fluidized-bed/cyclonic agglomerating combustor (AGGCOM) based on a combination of IGT technologies. In the combined system, solid, liquid, and gaseous organic wastes are destroyed efficiently. Solid, nonvolatile, inorganic contaminants are combined within a glassy matrix consisting of discrete pebble-sized agglomerates that are suitable for disposal in a landfill.

The first stage of the combustor is an agglomerating fluidized-bed reactor, which can operate under substoichiometric conditions or with excess air. The system can operate from

low temperature (desorption) to high temperature (agglomeration). The system can also gasify materials with high calorific values (for example, municipal solid wastes). With a unique fuel and air distribution, most of the fluidized bed is maintained at 1,500 F° to 2,000 F°, while the central hot zone temperature can be varied between 2,000 F° and 3,000 F°.

When contaminated soils and sludges are fed into the fluidized bed, the combustible fraction of the waste is rapidly gasified and combusted. The solid fraction, containing inorganic and metallic contaminants, undergoes a chemical transformation in the hot zone and is agglomerated into glassy pellets. The pellets are essentially nonleachable under the conditions



AGGCOM Pilot Plant

of the Toxicity Characteristic Leaching Procedure (TCLP). The product gas from the fluidized bed may contain unburned hydrocarbons, furans, dioxins, and carbon monoxide, as well as carbon dioxide and water, which are the products of complete combustion.

Product gas from the fluidized bed is fed into the second stage of the combustor, where it is further combusted at a temperature of 1,800 F° to 2,400 F°. The second stage is a high-intensity cyclonic combustor and separator that provides sufficient residence time (0.25 second) to oxidize carbon monoxide and organic compounds to carbon dioxide and water vapor. This stage has a combined destruction and removal efficiency of greater than 99.99 percent. Volatilized metals are collected downstream in the flue gas scrubber condensate.

The two-stage AGGCOM process is based on IGT's experience with other fluidized-bed and cyclonic combustion systems. The patented sloping-grid design and ash discharge port in this process were initially developed for IGT's U-GAS coal gasification process. The cyclonic combustor and separator is a modification of IGT's low-emissions combustor.

WASTE APPLICABILITY:

The two-stage AGGCOM process can destroy organic contaminants in gaseous, liquid, and solid wastes, including soils and sludges. Gaseous wastes can be fired directly into the cyclonic combustor. Liquid, sludge, and solid wastes can be co-fired directly into the fluidized bed. Solid particles must be less than about 6 millimeters in diameter to support fluidized bed operation; therefore, certain wastes may require grinding or pulverizing prior to remediation.

Because the solid components in the waste are heated above fusion temperature during the agglomeration process, metals and other inorganic materials are encapsulated and immobilized within the glassy matrix.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. Tests conducted in the batch, 6-inch-diameter, fluidized bed have demonstrated that agglomerates can be formed from the soil. The agglomerates, produced at several different operating conditions from soil spiked with lead and chromium compounds, passed the TCLP test for leachability.

A pilot-scale combustor with a capacity of 6 tons per day has been constructed (see photograph on previous page), and testing has produced samples of agglomerated soil. Future testing will focus on sustained and continuous operation of the pilot-scale plant using different types of soil, as well as other feedstocks. Tests with organic and inorganic hazardous waste surrogates admixed with the feed soil will also be conducted. A final report on the project has been submitted to EPA.

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INSTITUTE OF GAS TECHNOLOGY (Supercritical Extraction/Liquid Phase Oxidation)

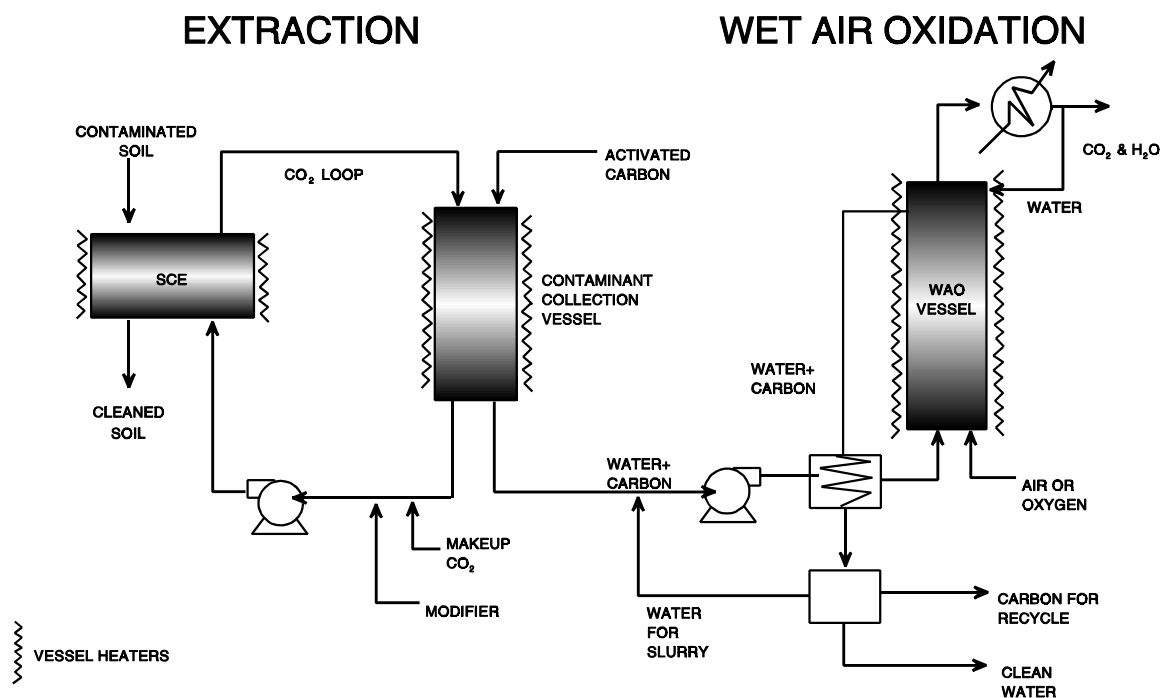
TECHNOLOGY DESCRIPTION:

The Institute of Gas Technology's (IGT) Supercritical Extraction/Liquid Phase Oxidation (SELPPhOx) process (see figure below) removes organic contaminants from soils and sludges and destroys them. SELPhOx combines two processing steps: (1) supercritical extraction (SCE) of organic contaminants, and (2) wet air oxidation (WAO) of the extracted contaminants. The two-step process, linked by a contaminant collection stage, offers great flexibility for removing and destroying both high and low concentrations of organic contaminants.

Combining SCE and WAO in a single two-step process allows development of a highly efficient and economical process for remediating contaminated soils. Supercritical extraction with carbon dioxide (CO_2) removes organic contaminants from the soil while leaving much of

the original soil organic matrix in place. The contaminants are collected on activated carbon in a contaminant collection vessel. The activated carbon with sorbed contaminants is then transported in an aqueous stream to a WAO reactor for destruction. Concentrating the organic contaminants on activated carbon in water provides a suitable matrix for the WAO feed stream and improves process economics by decreasing WAO reactor size. The activated carbon is regenerated in the WAO reactor with minimal carbon loss and can be recycled to the contaminant collection vessel.

The SELPhOx process requires only water, air, makeup activated carbon, and the extractant (CO_2). Primary treatment products include cleaned soil, water, nitrogen (from the air fed to the WAO step), and CO_2 . Organic sulfur, nitrogen, and chloride compounds that may be present in the original soil or sludge matrix are



Supercritical Extraction/Liquid Phase Oxidation (SELPPhOx) Process

transformed to relatively innocuous compounds in the product water. These compounds include sulfuric acid and hydrogen chloride, or their salts. The treated soil can be returned to the original site, and the water can be safely discharged after thermal energy recovery and minor secondary treatment. The gas can be depressurized by a turbo expander for energy recovery and then vented through a filter.

WASTE APPLICABILITY:

The SELPhOx process removes organic contaminants from soils and sludges, including chlorinated and nonchlorinated polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls, and other organic contaminants. The process is targeted toward sites that are contaminated with high levels of these organics (hot spots).

The SELPhOx process was accepted into the SITE Emerging Technology Program in July 1994. The primary objectives of the project are to (1) evaluate SCE's contaminant removal efficiency, (2) determine the potential for CO₂ recovery and reuse, and (3) determine destruction efficiencies of extracted contaminants in the WAO process. Analytical results from the project will provide the necessary information for the full-scale process design.

Laboratory-scale SCE tests have been completed using soils contaminated with PAHs. Operating conditions for the SCE stage and the activated carbon adsorption stage have been selected. A transportable field test unit was constructed and tested with PAH-contaminated soil. The final report has yet to be submitted by the developer.

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IT CORPORATION (Batch Steam Distillation and Metal Extraction)

TECHNOLOGY DESCRIPTION:

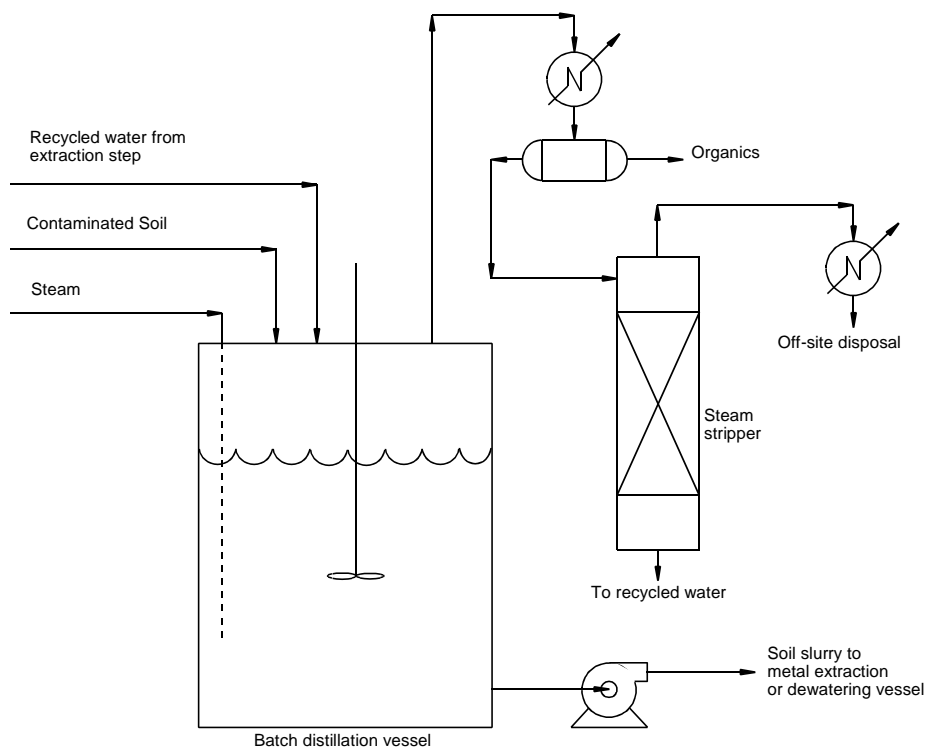
The batch steam distillation and metal extraction treatment process is a two-stage system that treats soils contaminated with organics and inorganics. The system uses conventional, readily available process equipment and does not generate hazardous combustion products. Hazardous materials are separated from soils as concentrates, which can then be disposed of or recycled. Treated soil can be returned to the site.

During treatment, waste soil is slurried in water and heated to 100° C. The heat vaporizes volatile organic compounds (VOC) and produces an amount of steam equal to 5 to 10 percent of the slurry volume. Resulting vapors are condensed and decanted to separate organic contaminants from the aqueous phase. Condensed water from this step can be recycled

through the system after soluble organics are removed. The soil is then transferred as a slurry to the metal extraction step.

In the metal extraction step, the soil slurry is washed with hydrochloric acid. Subsequent countercurrent batch washing with water removes residual acid from the soil. The solids are then separated from the final wash solution by gravimetric sedimentation. Most heavy metals are converted to chloride salts in this step. The acid extract stream is then routed to a batch steam distillation system, where excess hydrochloric acid is recovered (see figure below). Bottoms from the still, which contain heavy metals, are precipitated as hydroxide salts and are drawn off as a sludge for off-site disposal or recovery.

As a batch process, this treatment technology is targeted at sites with less than 5,000 tons of soil



Batch Steam Distillation Step

requiring treatment. Processing time depends on equipment size and batch cycle times; about one batch of soil can be treated every 4 hours.

WASTE APPLICABILITY:

This process may be applied to soils and sludges contaminated with organics, inorganics, and heavy metals.

The batch steam distillation and metal extraction process was accepted into the SITE Emerging Technology Program in January 1988. The evaluation was completed in 1992. The Emerging Technology Bulletin (EPA/540/F-95/509), which details results from the test, is available from EPA.

Under the program, three pilot-scale tests have been completed on three soils, for a total of nine tests. The removal rates for benzene, toluene, ethylbenzene, and xylene were greater than 99 percent. The removal rates for chlorinated solvents ranged from 97 to 99 percent. One acid extraction and two water washes resulted in a 95 percent removal rate for heavy metals. Toxicity characteristic leaching procedure tests on the treated soils showed that soils from eight of the nine tests met leachate criteria. Data were also collected on the recovery rate for excess acid and the precipitation rate of heavy metals into a concentrate.

Estimated treatment costs per ton, including capital recovery, for the two treatment steps are shown in the box below.

Batch Steam Distillation	
500-ton site	\$299-393/ton
2,500-ton site	\$266-350/ton
Metals Extraction (including acid recovery)	
500-ton site	\$447-619/ton
2,500-ton site	\$396-545/ton

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IT CORPORATION (Chelation/Electrodeposition of Toxic Metals from Soils)

TECHNOLOGY DESCRIPTION:

IT Corporation has conducted laboratory-scale research on an innovative process that removes heavy metals from contaminated soils and sludges by forming a soluble chelate. The metals and the chelating agent are then separated from the soils and recovered.

The treatment employs two key steps (see figure below): (1) a water-soluble chelating agent, such as ethylenediamine tetraacetic acid, bonds with heavy metals and forms a chelate; and (2) an electromembrane reactor (EMR) recovers the heavy metals from the chelate and regenerates the chelating agent.

Soils are screened before the chelation step to remove large particles such as wood, metal scrap, and large rocks.

The chelated soil is dewatered to separate the water-soluble chelating agent from the solid phase. The separated chelating agent, which contains heavy metals, is then treated in the

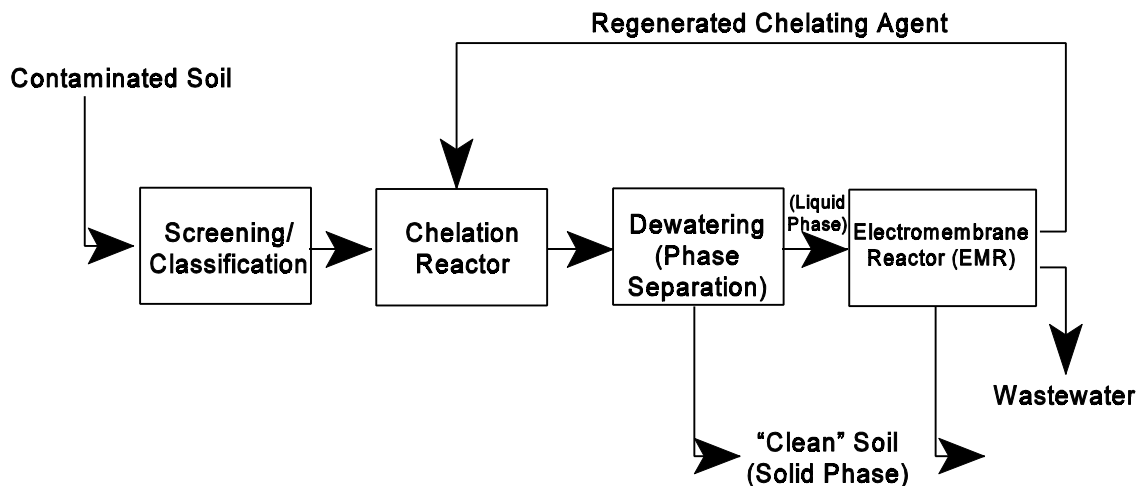
EMR. The EMR consists of an electrolytic cell with a cation transfer membrane separating the cathode and anode chambers.

WASTE APPLICABILITY:

The technology is applicable to a wide variety of metal-contaminated hazardous wastes, including soils and sludges. To date, IT Corporation has demonstrated the technology's effectiveness in removing lead and cadmium from soils and sludges.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1994. The Jack's Creek site, located near Maitland, Pennsylvania, was selected as a site for technology evaluation. The site operated as a precious and nonprecious metal smelting and nonferrous metal recycling operation from 1958 to 1977. A portion of the property is currently operated as a scrap yard. Lead concentrations in the contaminated soil used for the evaluation was



Simplified Process Flow Diagram of Treatment Process

approximately 2 percent. Toxicity characteristic leaching procedure (TCLP) analysis on the contaminated soil showed lead levels of 7.7 milligrams per liter (mg/L), which exceeds the regulatory limit of 5 mg/L. During the project, IT Corporation established appropriate conditions for lead removal and recovery from the soil and reduced TCLP concentrations of lead in the soil to below regulatory levels.

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IT CORPORATION (Mixed Waste Treatment Process)

TECHNOLOGY DESCRIPTION:

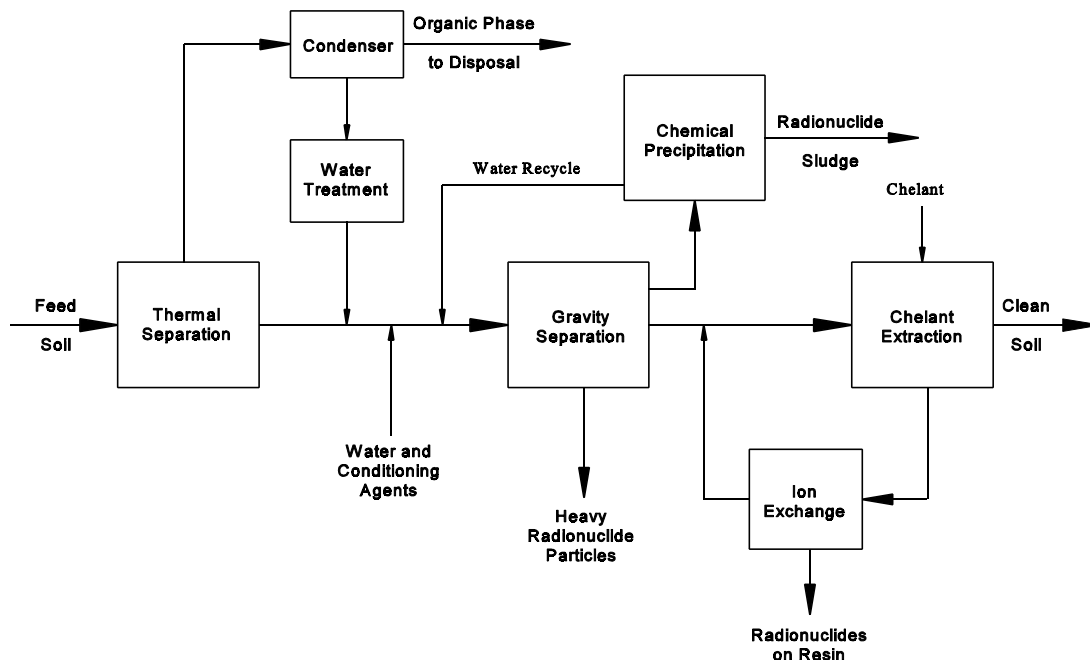
IT Corporation's mixed waste treatment process integrates thermal desorption, gravity separation, water treatment, and chelant extraction technologies to treat soils contaminated with hazardous and radioactive constituents. The process separates contaminants into distinct organic and inorganic phases that can then be further minimized, recycled, or destroyed at commercial disposal facilities. Decontaminated soil can then be returned to the site. Each technology has been individually demonstrated on selected contaminated materials. The process flow diagram below shows how the technologies have been integrated to treat mixed waste streams.

During the initial treatment step, feed soil is prepared using standard techniques, such as screening, crushing, and grinding to remove oversized material and provide a consistent feed material.

Thermal treatment removes volatile and semi-volatile organics from the soil. Soil is indirectly heated in a rotating chamber, volatilizing the organic contaminants and any moisture in the soil. The soil passes through the chamber and is collected as a dry solid. The volatilized organics and water are condensed into separate liquid phases. The organic phase is decanted and removed for disposal. The contaminated aqueous phase passes through activated carbon, which removes soluble organics, before the aqueous phase is combined with the thermally treated soil.

Inorganic contaminants are removed by three physical and chemical separation techniques: (1) gravity separation of high density particles (2) chemical precipitation of soluble metals and (3) chelant extraction of chemically bound metals.

Gravity separation is used to separate higher density particles from common soil. Radionuclide contaminants are typically found in



Mixed Waste Treatment Process

this fraction. The gravity separation device (such as a shaker table, jig, cone, or spiral) depends on the contaminant distribution and the physical properties of the thermally treated soil.

Many radionuclides and other heavy metals are dissolved or suspended in the aqueous media. These contaminants are separated from the soils and are precipitated. A potassium ferrate formulation precipitates radionuclides. The resulting microcrystalline precipitant is removed, allowing the aqueous stream to be recycled.

Some insoluble radionuclides remain with the soil following the gravity separation process. These radionuclides are removed by chelant extraction. The chelant solution then passes through an ion-exchange resin to remove the radionuclides, and the solution is recycled to the chelant extraction step.

The contaminants are collected as concentrates from all waste process streams for recovery or off-site disposal at commercial hazardous waste or radiological waste facilities. Decontaminated soil can be returned to the site as clean fill.

WASTE APPLICABILITY:

This process treats soils contaminated with organic, inorganic, and radioactive material.

STATUS:

The mixed waste treatment process was selected for the SITE Emerging Technology Program in October 1991. Bench- and pilot-scale testing was completed in late 1995; a report detailing evaluation results was made available from EPA in 1997. Individual components of the treatment process have been demonstrated on various wastes from the U.S. Department of Energy,

(DOE), the U.S. Department of Defense, and commercial sites. Thermal separation has removed and recovered polychlorinated biphenyls from soils contaminated with uranium and technetium. These soils were obtained from two separate DOE gaseous diffusion plants.

Gravity separation of radionuclides has been demonstrated at pilot scale on Johnston Atoll in the Pacific Ocean. Gravity separation successfully removed plutonium from native soils.

Water treatment using potassium ferrate formulations has been demonstrated at several DOE facilities in laboratory- and full-scale tests. This treatment approach reduced cadmium, copper, lead, nickel, plutonium, silver, uranium, and zinc to dischargeable levels.

Chelant extraction has successfully treated surface contamination in the nuclear industry for more than 20 years. Similar results are expected for subsurface contamination.

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IT CORPORATION (Photolytic and Biological Soil Detoxification)

TECHNOLOGY DESCRIPTION:

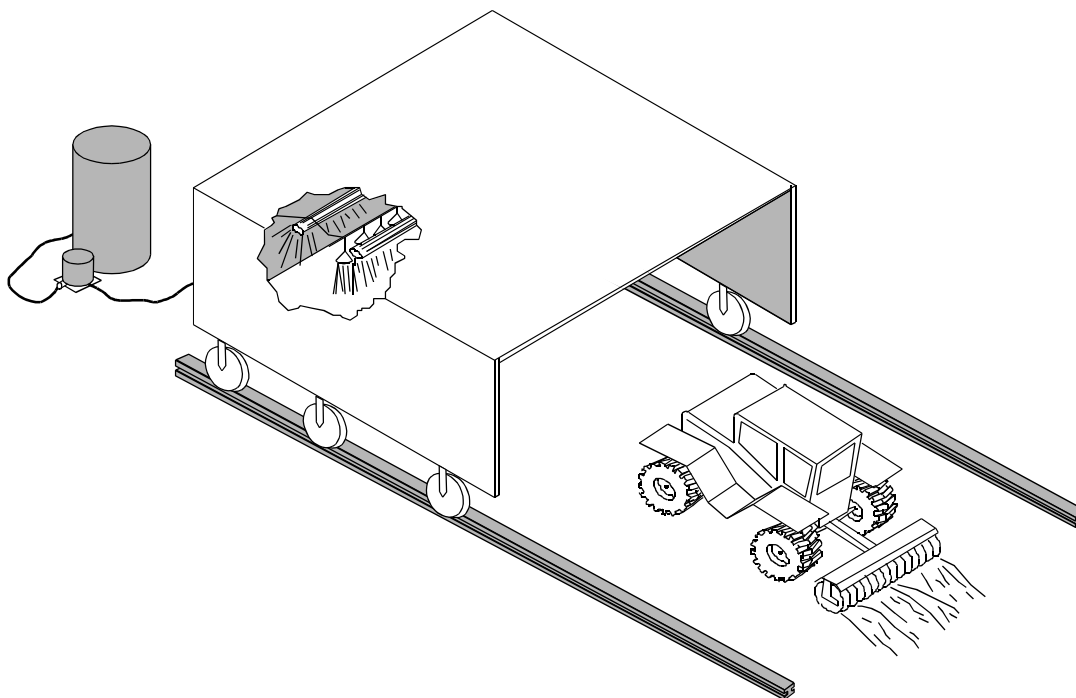
This technology is a two-stage, in situ photolytic and biological detoxification process designed for shallow soil contamination. The first step in the process degrades the organic contaminants with ultraviolet (UV) radiation. The photolytic degradation rate is several times faster with artificial UV light than with natural sunlight. The degradation process is enhanced by adding detergent-like chemicals (surfactants) to mobilize the contaminants. Photolysis of the contaminants converts them to more easily degraded compounds. Periodic sampling and analysis determines when photolysis is complete. Biodegradation, the second step, further destroys organic contaminants and detoxifies the soil.

When sunlight is used to treat shallow soil contamination, the soil is first tilled with a power

tiller and sprayed with surfactant. The soil is tilled frequently to expose new surfaces and sprayed often to promote the degradation process. Water may also be added to maintain soil moisture.

When UV lights are used, parabolic reflectors suspended over the soil increase the amount of UV irradiation (see figure below). After photolysis is complete, biodegradation is enhanced by adding microorganisms and nutrients and further tilling the soil.

When these techniques are applied to soils with deep contamination, the soil must be excavated and treated in a specially constructed shallow treatment basin that meets Resource Conservation and Recovery Act requirements. When soil contamination is shallow, photolysis and housing prevent contaminants from migrating to groundwater.



Photolytic Degradation Process Using UV Lights

The only treatment residuals of the process are soil contaminated with surfactants and the end metabolites of the biodegradation processes.

The end metabolites depend on the original contaminants. The surfactants are common materials used in agricultural formulations, the soils can be left on site.

WASTE APPLICABILITY:

This photolytic and biological soil detoxification process destroys organics, particularly dioxins such as tetrachlorodibenzo-p-dioxin (TCDD), polychlorinated biphenyls (PCB), other polychlorinated aromatics, and polynuclear aromatic hydrocarbons.

STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1989; the evaluation was completed in 1992. The Emerging Technology Report (PB95-159992) is available for purchase from the National Technical Information Services. The Emerging Technology Bulletin (EPA/540/F-94/502) and Emerging Technology Summary (EPA/540/SR-94/531) are available from EPA.

Bench-scale tests conducted on dioxin-contaminated soil showed that the effectiveness of surface irradiation to degrade TCDDs or PCBs is strongly influenced by soil type. Early tests on sandy soils showed greater than 90 percent removals for both TCDDs and PCBs. Using a 450-watt mercury lamp, the irradiation time was more than 20 hours for greater than 90 percent destruction of TCDD and more than 4 hours for greater than 90 percent destruction of PCBs. However, a high humic content decreased the effectiveness of the UV photolysis. Soil contaminated with PCBs in the bench-scale tests had a high clay content. The highest removal rate for these soils was 30 percent, measured over a 16-hour irradiation time. Bench-scale tests used a medium-pressure, mercury UV lamp; sunlight was ineffective. No significant improvement in PCB destruction was achieved using a pulsed UV lamp.

The process was also tested with Fenton's reagent chemistry as an alternate method of degrading PCBs to more easily biodegraded compounds. PCB destruction ranged from nondetectable to 35 percent. Data indicates that no significant change in PCB chlorine levels occurred during treatment.

Other studies examined PCB biodegradation in (1) soil treated with a surfactant and UV radiation, (2) untreated soil, and (3) soil known to have PCB-degrading microorganisms. Study results were as follows:

- PCB removal in the UV-treated soil, untreated soil, and soil with known biological activity was higher when augmented with an isolated PCB degrading microorganism.
- In the untreated soil, biphenyl was more efficient at inducing PCB degradation than 4-bromobiphenyl.
- For the treated soil, surfactant treatment may have inhibited microbial activity due to high total organic carbon and low pH.

Isolation and enrichment techniques have made it possible to isolate microorganisms capable of biodegrading PCBs in contaminated soil.

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